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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

CONTRIBUTIONS TO THE GEOLOGY OF WASHINGTON

Geology and Physiography of Central Washington

By GEORGE OTIS SMITH

Physiography and Deformation of the Wenatchee-Chelan District Cascade Range

By BAILEY WILLIS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

CONTRIBUTIONS TO THE GEOLOGY OF WASHINGTON

GEOLOGY AND PHYSIOGRAPHY OF CENTRAL WASHINGTON

BY

GEORGE OTIS SMITH

CONTENTS.

Page.

Introduction 9

Literature 10

Geology 13

  Formations 13

    Pre-Eocene 14

      Easton schist 14

      Peshastin formation 14

      Hawkins formation 14

      Igneous rocks 14

    Eocene 15

      Swauk formation 15

      Teanaway basalt 15

      Roslyn formation 16

      Manastash formation 16

    Miocene and later 16

      Yakima basalt 16

      Ellensburg formation 17

      Later lavas 18

      Pleistocene deposits 19

  Structure 19

    Mount Stuart quadrangle 19

    Ellensburg quadrangle 21

  History (summary) 21

Physiography 22

  Topographic descriptions 22

    Mount Stuart region 22

    Yakima region 23

  Cascade lowland 24

    Identification 24

    Development 26

  Cascade plateau 29

    Character of the uplift 29

    Varying degree of dissection 30

    River history 32

    Physiography of the Snoqualmie quadrangle 34

Résumé 38

ILLUSTRATIONS.

Page.

PLATE I. Map of central Washington 10

II. Yakima Canyon at Beavertail Bend 12

III. Geologic map of a portion of the Mount Stuart quadrangle 14

IV. Geologic map of a portion of the Ellensburg quadrangle 18

V. Physiographic sketch map of a portion of the Ellensburg quadrangle 26

VI. Map of Yakima Canyon, with geologic section 32

VII. Map of Snoqualmie quadrangle 36

FIG. 1. Contact of Ellensburg sandstone and Yakima basalt 27

GEOLOGY AND PHYSIOGRAPHY OF CENTRAL WASHINGTON.

By George Otis Smith.

INTRODUCTION.

Central Washington includes a part of two great topographic provinces, the great plain of the Columbia and the Cascade Range. The former, in its position and general desert-like character, suggests at once a resemblance to the Great Basin of Utah and Nevada; and the vastness of the desert plain is emphasized by the snowy peaks of the Cascades along its western border. These provinces are not to be regarded as unconnected in their geologic history, however great the contrast in their general features. The intermediate zone between the great plain on the east and the mountain range on the west is a strategic point for the investigation of the geologic structure and history and the interpretation of the present topography of both provinces. On the extensive basalt-covered plain monotony wearies the traveler, while on the rocky peaks of the Cascades the complexity taxes the powers of the observer.

Yakima River, an important tributary of the Columbia, drains a large area on the eastern slope of the Cascade Mountains, and in the medial portion of its course this river traverses a region which shares many of the features belonging to the two provinces mentioned above. The Mount Stuart and Ellensburg quadrangles[a] are situated close to the geographic center of the State of Washington and include an area of about 1,600 square miles. In the southern portion of this area the country is characterized by broad valleys and low, gently sloping ridges. The general absence of forest trees and the abundance of the sagebrush are other features that remind the traveler of the great plain to the east. In the northern part of the Mount Stuart quadrangle the ridges are of a bolder type and the extremely rugged topography of Mount Stuart and other portions of the Wenatchee Mountains suggests at once the main range of the Cascades. These two quadrangles have been surveyed both topographically and geologically, and the results of these surveys constitute the basis of the present paper.

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[a] Under the plan adopted by this survey for the preparation of a geologic map of the United States the entire area is divided into small quadrangles, bounded by certain meridians and parallels, and each is named from some well-known place or feature appearing in it.

In the preparation of this paper I have had the privilege of frequent conference with Mr. Bailey Willis. His familiarity with the area here described has given special value to his helpful criticism, which is gratefully acknowledged. Portions of the area described by Mr. Willis have also been visited by myself, and I believe the conclusions reached in his paper to be in general agreement with the results of the work in central Washington. The separation of the two areas and the fact that the field work was more or less distinct and conducted under different conditions led to the publication of our results as two papers, rather than as a joint contribution to the geology of the region. In the mapping of the Ellensburg quadrangle I was assisted by Mr. Frank C. Calkins.

The results of this survey have been published in the Ellensburg folio, No. 86, of the Geologic Atlas of the United States.

LITERATURE.

A glance at the literature which is available regarding this area will serve to show the present state of our knowledge of the geology and physiography of central Washington. Russell[a] records the occurrence of older crystalline rocks in this area, separated by an unconformity from overlying sediments of early Tertiary age. Above these, with another unconformity, is the great series of lava flows, named by Russell the "Columbia lava,"[b] above which is another sedimentary series of Miocene age, correlated by Russell with the John Day beds of Oregon. Professor Russell's determination of the age of the Cascade Range as post-Miocene[c] is provisional only, but the antecedent character of the main streams of the region is more definitely stated, as follows:

> "The evidence that the main drainage lines of central Washington were established before the present relief was initiated is cumulative and abundant. The rivers began to flow when Lake John Day was drained and had their courses determined by the slope of the surface of the bottom of the old lake. Since then mountain ranges have been formed by faulting, but the larger streams, i. e., the Columbia and Yakima, were able to cut down their channels as rapidly as the ridges were upraised athwart their channels."[d]

The structure of the range is thus described:

> "It seems probable that the Cascades are formed to a large extent of tilted blocks of basalt which were originally horizontal, and belong to the same series as the Columbia [River] lavas farther east, which have been, in comparison, only moderately disturbed. The Cascade Mountains, at least in the State of Washington, do not seem to have been formed mainly by the piling up of erupted material, as has been suggested in explanation of their origin farther south, but are due to the

---

[a] A geological reconnaissance in central Washington. Bull. U. S. Geol. Survey No. 108, pp. 20–25.

[b] This has later been termed by Russell the Columbia River lava.

[c] Ibid., p. 24.

[d] Ibid., p. 97.

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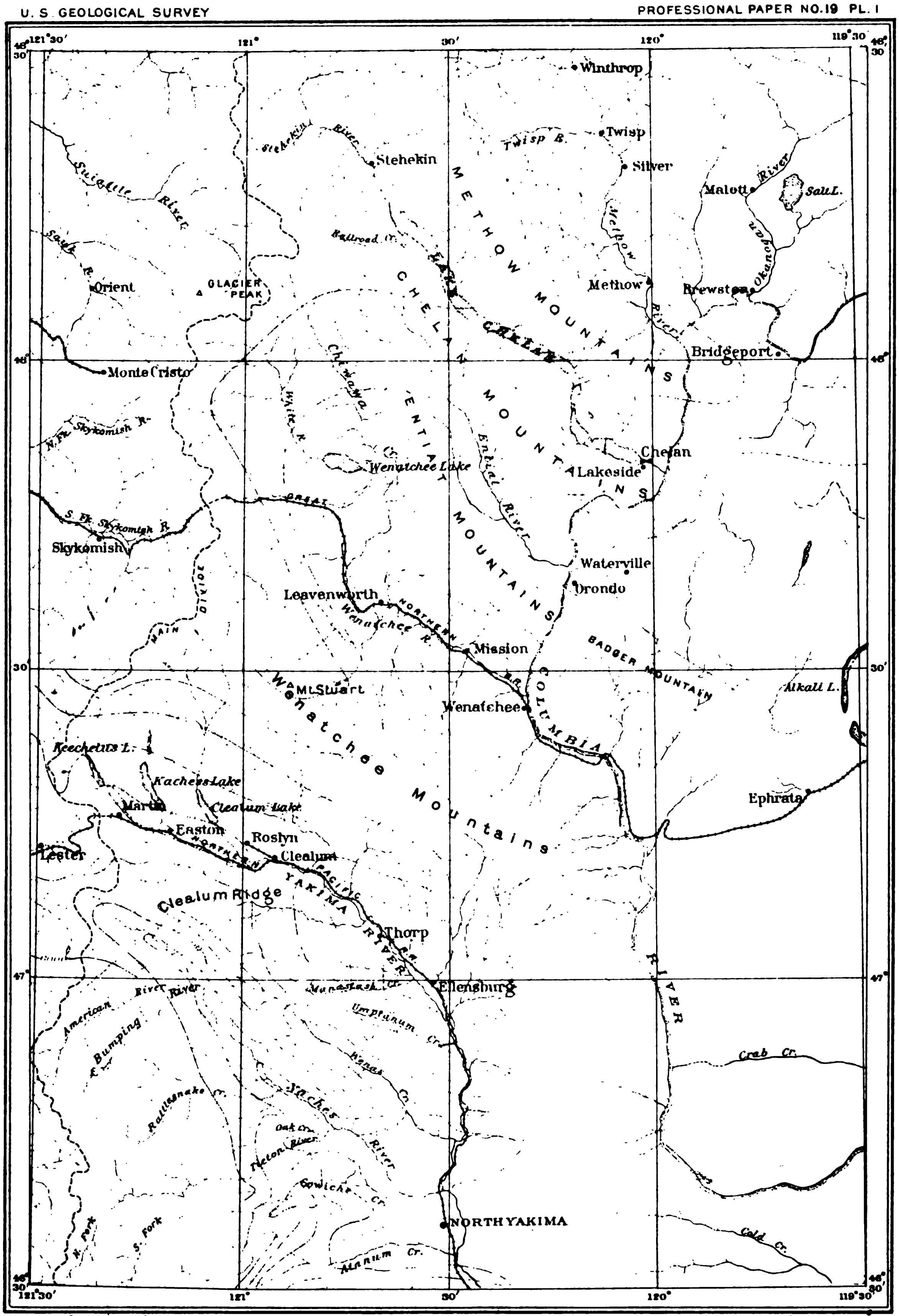

Drainage from topographic maps of the United States Geological Survey

Northern half by Bailey Willis
Southern half by George Otis Smith

MAP OF CENTRAL WASHINGTON

CONTOURS ON RESTORED WARPED SURFACE OF THE METHOW (PLIOCENE) PENEPLAIN

Scale

10 5 0 10 20 30 miles

1903

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uplifting and tilting of previously consolidated lava sheets, as well as of granite and coal-bearing strata, which occur high up on each flank of the mountain, and even form portions of the main divide. The great volcanoes which appear so prominent along the general trend of the range are secondary to the main mountain building."[a]

In a later publication[b] Professor Russell describes more fully the Columbia River lava, and states that its maximum thickness in the Snake River region is over 5,000 feet.[c] The geologic history of the whole of the Columbia Plains area is sketched.[d] In early Tertiary times there were mountains in what is now northern Washington and eastern Idaho, but the central and southern portions of the Cascades were not yet in existence. In the area now including the great plain of the Columbia sedimentation went on in early Tertiary times, clays and sands being deposited, with accumulations of vegetable matter later changed to coal. Upheaval of these sediments "brought these once level sheets of rock above the sea and raised them into a mountain range, the southern Cascade." Erosion followed this upheaval, and later came the eruptions of the basaltic lavas which were spread over thousands of square miles. Succeeding the volcanic outbursts came lacustral sedimentation in broad lakes, probably formed "by the upheaval of the Cascade Mountains." These Miocene sediments are those which Professor Russell earlier called the John Day. Since the draining of the Miocene lakes Snake River has performed an immense task, having carved in the basalt plateau a gorge about 15 miles broad at the top and in places about 4,000 feet deep.

A later paper gives a fuller development of Professor Russell's[e] interpretation of the geologic history of the Cascade Range. The geologic formations are more fully described, mention being made of the older metamorphic schists, the igneous rocks, granite, greenstone, and serpentine, the sedimentary rocks of pre-Cretaceous, Cretaceous, and Tertiary age, and the Columbia River lava and volcanic rocks of Glacier Peak. On the subject of the structure of the northern Cascades Professor Russell says: "It will be seen that the structure of the range is highly complex, and is by no means a single great, north-south anticline, or a simple monoclinal block sculptured by erosion."[f] Attention is also called to lateral folds and faults on the eastern side of the range in central Washington, and the age of these secondary disturbances is shown to be late Tertiary or post-Tertiary, and apparently contemporaneous "with the latest great upward movement in the Cascade Mountain mass." Again the author notes the antecedent character of the Columbia and Yakima, which cross in narrow gaps these "tilted blocks." The origin of the range is thus stated: "The Cascade Mountains, as we know them, seem to have been carved from an upraised peneplain. This plain we term the Cascade peneplain, and the plateau may be conveniently designated the Cascade plateau."[a] Russell's hypothesis of a Cascade peneplain rests upon the presence of truncated folds, stream erosion having reduced the whole region nearly to sea level. "During the later portion of the time of base-leveling, the widely spread sheets of Columbia [River] lava were poured out. The date of the period of planation is shown approximately by the fact that folded beds of Eocene age were truncated. The broad peneplain must therefore have reached its greatest degree of perfection in late Tertiary time, probably extending into the Pleistocene."[b] It will be noted that the epoch of great basalt eruptions is thus included in the period of reduction to base-level.

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[a] A geological reconnaissance in central Washington· Bull U. S. Geol. Survey No. 108, p 30.

[b] A reconnaissance in southern Washington. Water-Sup. and Irr. Paper No. 4, U. S. Geol Survey.

[c] Ibid., p. 42. [d] Ibid., pp. 88–93.

[e] A preliminary paper on the geology of the Cascade Mountains in northern Washington· Twentieth Ann. Rept. U. S. Geol Survey, pt 2.

[f] Ibid. p. 137.

In brief, Professor Russell's "conception of the origin of the larger topographic features of the northern Cascades is that the region, having a complex structure, was reduced by erosion to a condition of low relief, and at a later date than the folding of the Tertiary sediments and the outspreading of the Columbia [River] lava was broadly upraised about 7,500 feet in the axial region. The courses of the larger streams were then established and the plateau was deeply dissected."[c] The author then describes the extent to which the dissection of the Cascade plateau has proceeded, and mentions in this connection the striking feature that the larger streams of central Washington, of which Yakima River is the best example, have carried the low grade far back toward the axis of the range.[d] It is also noted that the courses of the streams are in a marked way independent of the structure of the upraised region.[e]

In attempting to determine the position of the upraised peneplain surface, Professor Russell observes that no recognizable flat-topped remnants of the original plateau are to be found in the more elevated portions of the range, but that the sharp-crested ridges and acute peaks may testify to a general diminution in height in the case of the soft rocks, while the harder rocks, such as the granites, more nearly approximate the original elevation of the plateau. Such evidence that the surface of the Cascade plateau has been somewhat lowered by erosion is not thought by Professor Russell to be conclusive.[f]

In a later paper,[g] Professor Russell goes into a discussion of the character of the plateau which was built up by the Columbia River lava. Taking as a premise the general parallelism of the succession of the lava flows as exposed in canyon walls, he argues that during the period of eruption there were no general movements such as would cause unconformities within the Columbia River series. This lava is

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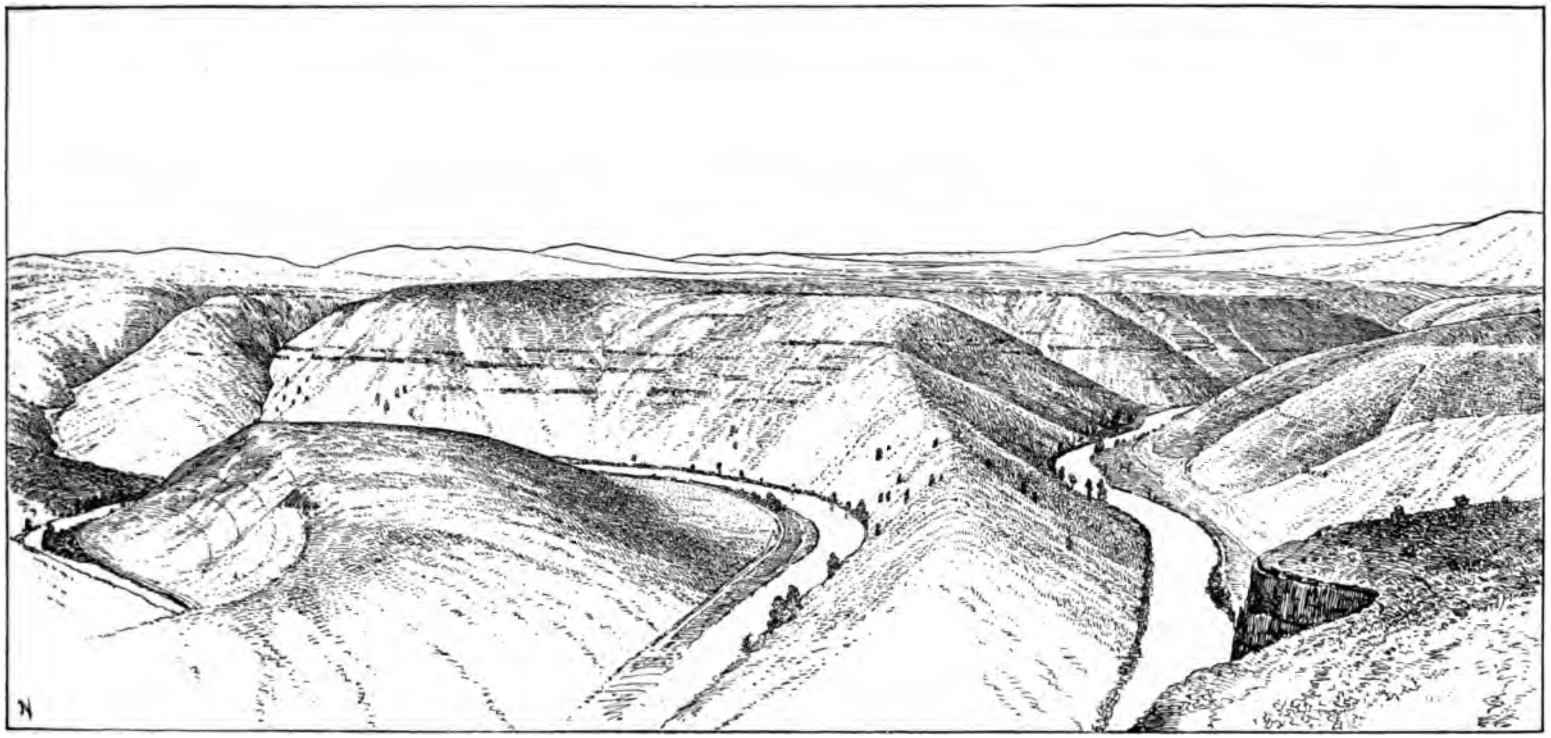
[a] A preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept., U. S. Geol. Survey, pt. 2, p. 140.

[b] Ibid., p. 144. [c] Ibid., p. 142. [d] Ibid., p. 145. [e] Ibid., p. 150. [f] Ibid., p. 141.

[g] The geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 54, U. S. Geol. Survey.



YAKIMA CANYON AT BEAVERTAIL BEND.

believed to have been poured out in a "series of vast inundations over a deeply eroded land surface." Since the series is in places over 4,000 feet thick, if there was no subsidence during the period of eruption the surface of the last flow must have had at least that elevation above the sea. That there were no movements producing a depression during the period of eruption is believed by Professor Russell on the grounds that there are no marine sediments interbedded with the lava sheets; and neither have unconformities been detected in the eastern portion of the area covered by the Columbia River lava. On this account the horizontal surface of the lava plateaus in eastern Washington and Oregon and the adjacent part of Idaho should have an elevation of at least 4,000 feet or more above the sea. On the contrary, the elevation of such plateaus is between 3,000 and 3,300 feet, and this difference of approximately 1,000 feet is supposed by Russell to indicate a general subsidence of the eastern portion of the lava region. In his discussion of the drainage of this area Professor Russell, however, still regards Snake River where it crosses the lava plateau as an antecedent stream.

GEOLOGY.

FORMATIONS.

The two quadrangles which this paper chiefly describes contain rocks of various ages. The geologic section is fairly representative for the whole State, and its discussion is therefore of more than local interest. Pls. III and IV show the geology of characteristic portions of the two quadrangles. The separation of the older and the younger rocks is an obvious one, and would be noted by any close observer. In a general way it may be stated that within this area the oldest rocks lie to the north, in the vicinity of Mount Stuart, and the youngest to the south. To describe this section as a southward-dipping monocline, however, would be misleading, since this would disregard the many marked unconformities which separate the different formations.

In this chapter the rocks will be grouped according to age as pre-Eocene, Eocene, and Miocene and later. The first class includes rocks that are unfossiliferous and plainly more or less altered, with intrusive rocks predominating. Above the base of the Eocene the rocks are fresher in appearance and contain fossils by which their exact age is determined, while the igneous rocks are chiefly surface volcanics. The Miocene rocks are so fresh appearing that in places it is difficult to distinguish them from recent deposits. Thus it will be seen that the grouping adopted is a natural one.

These formations are more fully described in the Ellensburg folio, No. 86, and the Mount Stuart folio, which is in the course of publication.

PRE-EOCENE.

Easton schist.—This is probably the oldest rock to be found in central Washington. It is not shown upon either of the accompanying geologic maps, but occupies a few square miles in the southwestern part of the Mount Stuart quadrangle and extends westward into the Snoqualmie quadrangle. Here it forms in large part the southern wall of the Yakima Valley, and is especially prominent southeast of the town of Easton.

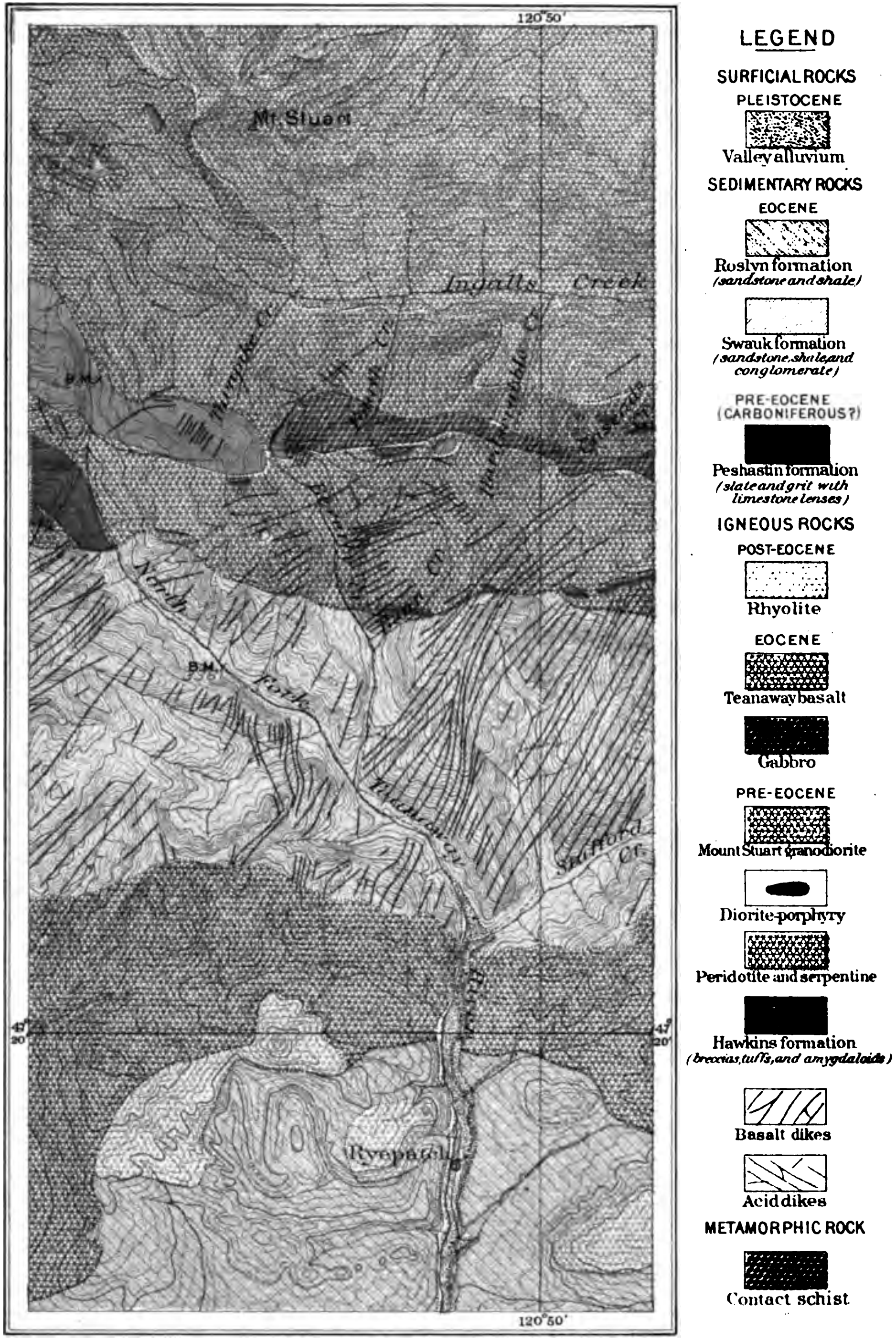
The Easton schist is typically a silver-gray or green rock, composed principally of quartz and micas. The schist is extremely crumpled and is gashed and seamed with veins and stringers of quartz. Associated with this quartz-mica rock are other schists, containing hornblende or epidote, while quartzite is also found. The occurrence of this quartzite in close association with the schists is believed to indicate the sedimentary origin of the schists.

Peshastin formation.—South of the Mount Stuart massif occurs a series of sedimentary rocks that may rank next to the Easton schist in age. These are black slate, with grit or conglomerate, and bands of black chert and lenses of light-gray limestone interbedded with the slate. In places these rocks show metamorphism by the igneous rocks with which they are in contact, and nowhere in the many exposures of this formation have any traces of fossils been discovered.

It seems plausible to assign this sedimentary formation to the Paleozoic, and it is possible that it is of Carboniferous age. This age determination rests simply upon a general resemblance of the formation to the Carboniferous rocks of the Sierra Nevada and of British Columbia. Rocks also strikingly similar to the Peshastin formation are found in the Blue Mountains of Oregon and in the Okanogan Valley in northern Washington.

Hawkins formation.—This is a volcanic series of flow-breccias, tuffs, and amygdaloids. These rocks are dark colored, green, or purple, extremely altered, and everywhere exerting a marked influence upon the topography, rough slopes with ragged crests being characteristic of this formation. While composed largely of secondary minerals, these lavas and tuffs preserve their original textures, and microscopic study shows that the rocks were originally composed of augite and plagioclase, with diabasic texture. The whole series undoubtedly represents surface lava flows with associated tuffs. The Hawkins and Peshastin formations have been intricately mingled by close folding, while subsequent intrusions of igneous rock have also obscured relations.

Igneous rocks.—Surrounding the older rocks just described are great belts of serpentine. This rock is intrusive, and its extent within the Mount Stuart quadrangle is important, since it covers nearly 50 square miles. The serpentine is an altered phase of peridotite, the latter rock being found in its original state at many



GEOLOGIC MAP OF A PORTION OF MOUNT STUART QUADRANGLE
WASHINGTON

Topography by G.E. Hyde

Geology by George Otis Smith
assisted by G.C. Curtis

Scale
1 0 1 2 MILES
Contour interval 100 feet

JULIUS BIEN & CO LITH. N.Y.

places in the area. No rock can be more varied in color or in physical characters than is this serpentine. It ranges from bright red to light green in color, and forms bold crags with gigantic talus blocks below, or rounded hills covered with fine shingle resembling broken glass.

The serpentine and older rocks in which it is intruded contain gold and copper veins. Locally such veins have been found to be very rich, but the amount of low-grade ore far exceeds these bonanzas.

This serpentine is intrusive in the Peshastin and Hawkins formations, but is itself cut by dikes of light porphyritic rock. These latter are doubtless connected with the great batholith which forms Mount Stuart. The rock of the batholith is a typical granodiorite, often containing quartz, but too basic to be called a granite. It is a gray granular rock, quite granitic in appearance. Generally fresh and unaffected by surficial alteration, its constituent minerals can be seen to be white feldspar, black mica, and hornblende, with a few grains of quartz. The granodiorite is everywhere massive, but is jointed and sheeted, this feature giving rise to the spire and minaret details so characteristic of the crest line of Mount Stuart. Dikes of the granodiorite can be traced extending out into the serpentine, so that it is plainly the youngest of the pre-Eocene rocks.

EOCENE.

Swauk formation.—The oldest of the four Eocene formations is the Swauk formation, a series of sandstone, conglomerate, and shale, measuring in places at least 5,000 feet in thickness. The age is definitely determined as early Eocene by the fossil flora, and the basal beds are seen to be separated by a great unconformity from the formations upon which they rest. The conglomerate beds are mostly in the lower part of the section and the basal conglomerates are often peculiar in that the pebbles and bowlders are derived almost wholly from the rock upon which the conglomerate rests. Thus, the conglomerate may be composed of granodiorite bowlders in an arkose matrix or of serpentine blocks embedded in a sand of the same composition. The sandstone is for the most part arkose in character, although to the east the sediment shows better sorting and is more quartzose. The shale is often quite carbonaceous and rich in fossil leaves.

This formation is of economic importance from the gold veins it contains in the Swauk Basin. Most of the gold, however, is found in placers, but the gravels have all been derived from the Swauk formation and the gold is coarse and has not been carried far from the parent ledge.

Teanaway basalt.—Overlying the Swauk sandstone and separated from it by a slight unconformity is a volcanic formation. The Teanaway basaltic series comprises lava flows and interbedded tuffs. The basalt is black and very compact and makes a prominent rock. The tuffs are very irregular in their distribution and the thickness of the whole series varies within the area from thousands of feet to a few hundred.

This basalt has been termed by Russell the lowest or first sheet of Columbia River lava, but its importance in the stratigraphy of the region seems to warrant a more definite separation from the Miocene lava to be described later. The most striking feature of the Teanaway basalt is the occurrence of hundreds of dikes which cut through the underlying Swauk formation and connect with this surface flow. The opportunity is afforded for observing almost diagrammatically the evidence that these basalt flows were erupted through many fissures, and for the most part the eruption appeared to be unaccompanied by any disturbance of the underlying rocks.

Roslyn formation.—This sedimentary formation overlies the basalt without any apparent structural break, but also without any evidence of transitional sedimentation of interbedded sands and tuffs. A few pebbles of basalt in the basal beds show that locally there may have been erosion of the lava before the sedimentary beds began to be deposited. The Roslyn formation contains sandstones and shales, resembling the earlier Eocene sediments somewhat. Carbonaceous material becomes more important in the upper portion of the formation, where there are several beds of coal. The Roslyn coal seam is of commercial importance, and excellent steam coal is mined in quantities that give the Roslyn mine the first place among the coal mines of Washington.

Manastash formation.—So far as known this formation is limited to the southwestern part of the Mount Stuart quadrangle and the adjacent portion of the Snoqualmie quadrangle. It is a series of sandstone, shale, and conglomerate beds, containing some seams of carbonaceous material, mostly bone. Fossil plants from the shales determine the age of the formation as Upper Eocene, and it is therefore to be correlated with the Clarno formation of the John Day Basin. Although these beds are somewhat younger than the Roslyn formation, which occurs a few miles to the north, the Manastash rests directly upon the old Easton schist, and this relation is believed to indicate nondeposition of the earlier Eocene sediments in this area.

MIOCENE AND LATER.

Yakima basalt.—This basalt of Miocene age covers a considerable area in the Mount Stuart quadrangle and the larger part of the Ellensburg quadrangle. It extends to the northeast, east, and south of these quadrangles, and also forms a portion of the higher part of the range west of the Ellensburg quadrangle. The base of this great series of lava flows is exposed at many points in the Mount Stuart quadrangle, and the lavas are here seen to rest unconformably upon the Eocene formations. This unconformity between the Yakima basalt and the Manastash formation fixes the age of the lava as early or middle Miocene. It is, in view of the age determination, possible for this formation that the name Yakima has been applied to it. In earlier reports on central and southeastern Washington, Professor Russell applied the names Columbia lava and Columbia River lava to this rock. He, however, included not only the Miocene but also the Eocene and possibly the Pliocene basalts, as well as the hypersthene-andesite occurring along Naches River, which will be mentioned later as of Pleistocene age. It became necessary in course of detailed areal mapping to separate these various igneous rocks, and therefore the name Yakima has been applied to this formation, which includes only the basalt flows and interbedded pyroclastics which are of Miocene age and thus constitute a series that can be taken as a unit since it represents the products of a volcanic activity uninterrupted by any other important geological process. The Yakima basalt is a normal feldspar basalt containing the usual constituents, plagioclase, augite, and olivine. It is commonly a glassy lava, and in some localities large masses of pure basalt glass can be found. The rock is always dull in color and no crystals can be distinguished except by means of the magnifying glass. In a few localities, notably Bald Mountain, in the Ellensburg quadrangle, the series includes large quantities of fragmental material, the yellowish tuffs including irregular blocks of jet-black glass, some of which undoubtedly represent bombs ejected from the center of eruption. Along Yakima River the tuff beds and scoriaceous lavas are less common than the compact lava.

The number of lava flows in this series varies widely in different parts of the area. At no point is the whole series exposed. The sections shown in Yakima Canyon, where over 2,000 feet of basalt are exposed with neither the top nor base of the series visible, indicate that the actual thickness of the Yakima basalt is probably to be measured in thousands of feet, and 5,000 feet is undoubtedly a conservative estimate. The columnar structure is the most noticeable feature of the basalt where it is exposed in the canyon walls.

In a portion of the Ellensburg quadrangle slightly later flows of basalt occur interbedded with the sandstone which overlies the Yakima basalt. These have been included in the Wenas basalt, which is a formation of only local importance. Similar sheets of basalt are doubtless to be found in other portions of the great area covered with Miocene basalt.

Ellensburg formation.—The only formation in central Washington which is known definitely to be of Miocene age is the Ellensburg sandstone. Collections of fossil leaves made by Professor Russell in 1892 near Ellensburg and by myself in 1900 in Kelly Hollow have afforded material for the determination of the age of the formation, which Dr. F. H. Knowlton fixes as late Miocene. This determination correlates the Ellensburg formation with the Mascall formation of the John Day

Basin in Oregon. The Ellensburg formation also resembles the Mascall in its composition. Both formations are composed largely of volcanic sediments, the sandstones and shales consisting of the finely comminuted andesitic material and the conglomerates containing pebbles and bowlders of andesitic lavas. In both cases the lava from which the sedimentary material was derived is not exposed within the area where the sedimentary rocks have been studied. This volcanic series doubtless occurs in the higher parts of the range to the west.

Along Naches River over 1,500 feet of the Ellensburg formation are exposed, and the formation is characterized by coarseness of material, together with its prevailing andesitic composition, and also the common occurrence of stream bedding. A section of this formation exposed at White Bluffs, on Columbia River, is described by Professor Russell[a] as consisting of "fine, thin-bedded sand and clay, with layers of pure white volcanic dust." The field evidence, therefore, indicates that in the Yakima region the Ellensburg formation is to be considered as of fluviatile origin, while farther east along the Columbia the formation is plainly of truly lacustrine type. The cross stratification or stream bedding shows that the material was distributed by eastward-flowing streams. These stream sediments vary considerably in thickness within short distances, as would be expected, and at some points the stratification is so confused that individual beds can not be traced far. At localities, both in the Ellensburg and the Mount Stuart quadrangles, bowlders of andesite measuring at least 5 feet in diameter have been found in the Ellensburg conglomerate, proving that powerful currents must have transported the material.

Later lavas.—The lava from which the Ellensburg sediments were derived was light-colored and contained hornblende as an original constituent. Later lavas of a somewhat different type occur in central Washington. The most prominent of these is the hypersthene-andesite which forms a long lava stream extending from the Tieton Basin west of the Ellensburg quadrangle down Tieton Canyon and along the Naches Valley nearly to Yakima River. This lava was erupted after the basalt and Ellensburg rocks had been uplifted to their present positions, and at a time when the topography was essentially the same that it is to-day. The lava is, therefore, of Pleistocene age, and where not exposed to erosion by Tieton River the lava stream preserves the form which it took when it came to rest. The surface of the andesite plateau between Naches River and Cowiche Creek is exceedingly hummocky and full of undrained basins, while its margins, which have been affected by stream erosion, show the radiating columns into which the lava parted at the time of its consolidation.

Somewhat different lavas occur on the middle fork of Teanaway River, where rhyolitic rock is seen to rest upon the eroded surface of the older rocks. The age of

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[a] Bull. U. S. Geol. Survey No. 108, p. 97.

this lava is somewhat problematical, but evidently it is considerably younger than the Eocene rocks with which it is in contact.

Pleistocene deposits.—In the heart of the Cascade Range the valleys of the larger streams exhibit abundant evidence of glaciation. Within the area here described glacial deposits are not found except in the vicinity of Mount Stuart, which was a local center of glaciation. The valleys of Yakima River and most of its tributaries within the Mount Stuart quadrangle are gravel filled. These valley gravels attain great prominence in the upper valley of the Yakima and plainly once filled it to a considerable height, and diamond-drill records indicate that the river has not yet reached its former floor. The gravel terraces constitute a noticeable feature here, but are much less important than similar terraces upon the Columbia, which will be mentioned by Mr. Willis. In the Swauk drainage basin these terrace gravels are auriferous and have been mined for many years.

STRUCTURE.

Certain of the structural features have been mentioned in the foregoing description of the formations. A more complete statement of what has been learned concerning the geologic structure of the region will be given here, since the area affords excellent opportunities for studying the course of events in the dynamics of the mountain building. The two quadrangles present two types of structure, but both are representative for the Cascade Range.

MOUNT STUART QUADRANGLE.

The oldest rocks were intricately folded and faulted before the intrusion of the peridotite, and this accounts for the greater metamorphism which characterizes the schists, slates, and greenstones. The intrusive peridotite, now largely altered to serpentine, appears to have suffered similar dynamic action, but its record of deformation is doubtless much less significant. The rock is commonly crushed and sheared, but this condition indicates rather a lack of resistance on the part of the soft serpentine than intensity of the deformation forces. In fact, in large measure, the development of the zones of sheared material within the serpentine mass may have been due to the expansion incident upon the serpentinization of the peridotite. This alteration, with the resulting crushing, is known to be pre-Eocene in age, since the bowlders with slickensided surfaces, so characteristic of the zones of shearing, are found in the basal conglomerates of the Swauk formation.

The jointing of the granodiorite is its only structural feature, since nowhere is the rock schistose. This batholithic intrusion doubtless played a considerable part in the pre-Eocene structure of the region, but no deformation of the older rocks can be definitely traced to this igneous rock, unless the hydrothermal alteration of the peridotite may be attributed to the intrusive granodiorite. The presence of small dikes extending from the latter rock into the adjacent serpentine shows the absence of any later differential uplift of the massive granodiorite.

The earlier Eocene rocks appear to have been subjected to deformation soon after their deposition. The folds are open, with steep inclination of the strata exceptional. Within the area south of the Mount Stuart massif, a half dozen folds may be traced, the anticlines and synclines having axes which trend northwest-southeast. This structure, in part at least, antedates the eruption of the Teanaway basalt, since that rock lies upon the somewhat eroded folds of the Swauk sandstone. Later, however, these folds may have been further developed.

The manner in which the rocks of the Swauk formation nearly encircle the Mount Stuart massif suggests that this forms the center of a great dome-shaped uplift, with the Tertiary formations dipping outward. The areal distribution favors this simple explanation of the structure, but detailed study of the various formations makes it plain that a careful distinction must be made between the different movements that have contributed to the sum total of deformation. The attitude of the Mount Stuart massif at the commencement of the Eocene sedimentation can not be determined, except that this mass of granodiorite is known to have furnished the bulk of the detritus for the Swauk sediments. These strata on the south side of Mount Stuart then became folded, as has just been described, and uplifted so as to suffer erosion. If the structure developed at this time may be determined by the distribution of the basaltic lavas which flowed out in the succeeding epoch, it appears that there was not only an elevation in the vicinity of Mount Stuart, but also on the eastern and the southern part of the Mount Stuart quadrangle. The rise of the Wenatchee Mountains dome does not appear to have been so prominent a feature at this time as the development of an east-west trough in the central portion of the Mount Stuart quadrangle. In this depression, the molten lavas consolidated and the tuffs were laid down, and later the Roslyn sediments were deposited, the latter formation possibly covering in its original extent an even more limited area than did the Teanaway basalt.

Clealum Ridge, which bounds the Yakima Valley on the south, has certain topographic characters suggestive of a fault scarp. The structural relations show, however, that this marks the southern side of the syncline developed in the Teanaway and Roslyn formations, and its topographic prominence is due to the older rocks which rise here above the Eocene strata to the north. In middle Miocene time this ridge had much the same relative prominence, as is shown by the way the Yakima basalt abuts against and caps it, while filling the neighboring depressions. This post-Roslyn folding may have been coincident with the deformation of the Manastash strata, and thus belongs to the close of the Eocene period.

ELLENSBURG QUADRANGLE.

The post-Miocene deformation can be studied best in this quadrangle, where only Miocene formations are present. Yet, while pre-Miocene structures can thus be avoided here, it is necessary to distinguish between the flexing or moderate folding to which the Yakima basalt and the Ellensburg sediments were subjected soon after the deposition of the latter, from a later movement which affected the same rocks. These later structural features are so closely connected with the topographical features of the area that their discussion will be given under the heading "Physiography."

In the present connection, however, it may be well to call attention to a certain structural feature of the Yakima basalt. This is the almost universal occurrence of parting or jointing in the rock, by which the lava sheets are divided into the typical basaltic columns. This contraction parting took place normal to the surface of the lava flow, so that where the basalt has its original position undisturbed the joints are vertical. The presence of innumerable joints of this character, of course, would greatly facilitate the flexing of the basalt sheets, and, since the Yakima basalt is the more important formation in the Yakima region, this feature must not be disregarded in any consideration of the deformation of this area. Furthermore, this may serve to explain why the post-Miocene deformation, which will later be described as taking place at the surface, was not of the nature of faulting as that term is generally accepted. The structural ridges are not "tilted blocks" but anticlines.[a]

HISTORY.

The geology of central Washington may be best summarized by a brief résumé of the geologic history of the area.

The oldest rocks, probably of Paleozoic age, furnish a record of sedimentation and volcanism, but this record has been greatly obscured by the altered condition of these rocks. This metamorphism in turn tells of the orogenic movements to which the rocks have been subjected and of the action of intrusive magmas.

The great intrusions of peridotite and granodiorite probably belong to the Mesozoic, and were events of the first importance in the history of this portion of the Cascade Range. The period of erosion subsequent to these intrusions was of sufficient length to allow these deep-seated bodies to be uncovered and deeply dissected.

From these eroded older rocks was derived the material for the Eocene sediments, and the process of sedimentation appears to have been a rapid one within this area, since several thousand feet of granitic sands and other sediments were deposited in early Eocene time, before uplift again inaugurated erosive activity.

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[a] This absence of faults in this area has been discussed in a recent paper by the author—Anticlinal mountain ridges in central Washington Jour Geol Vol XI 1903 pp 166–177

Then began the first basaltic eruptions, the forerunners of the greater volcanism of the Miocene. This volcanic activity was succeeded by the quieter processes of sedimentation, by which the Roslyn sandstone was deposited in middle Eocene time. Somewhat later, in an adjacent area, the deposition of the Manastash sediments took place, and the Eocene period closed with the uplift and folding of all of these Eocene formations.

Erosion continued well into the Miocene within this area, but ceased with the beginning of the great eruption of basalt, the many flows of which covered the greater part of central Washington like a molten sea. Immediately succeeding this epoch of volcanism came the deposition of the Ellensburg formation, thick deposits of stream sands and gravels, brought down from a volcanic area to the west.

Mountain-building movements followed this sedimentation of the later Miocene, and again erosion began to cut away what had been uplifted. The Pliocene and post-Pliocene history is recorded in the topography, and will therefore be discussed in the following chapter.

Even this brief summary is sufficient to indicate how eventful has been the geologic history. Especially in Tertiary time is it true that this region has been one with relatively many changes. The many well-marked unconformities testify to the frequency of these geologic revolutions, so that geologic formations are easily separated upon the basis of structural breaks, whereas in other provinces such subdivision would need to be based wholly upon paleontologic evidence.

PHYSIOGRAPHY.

TOPOGRAPHIC DESCRIPTIONS.

MOUNT STUART REGION.

Mount Stuart, 9,470 feet high, lies 15 miles east of the main crest of the Cascade Range, and forms the culminating peak of the Wenatchee Mountains. These mountains constitute a secondary range transverse to the general trend of the Cascades, but are characterized by the same rugged topography as the main range. The mountain crests are deeply carved into spires and crags, while precipitous slopes descend into glacial amphitheaters where remnants of glaciers still persist. South of Mount Stuart, and extending almost to Yakima River, there is a belt of hardly less rugged topography. Here the valleys are deep and canyon-like and the divides are sharp and narrow. Dissection has apparently reached the extreme limit, and the topography may be termed mature. The gradient of the streams is largely determined by rock hardness, and many of the minor topographic features, such as peaks and gaps in the crest lines of ridges, are also referable to varying resistance of the different rocks. Pl. III is a map of a portion of the Mount Stuart quadrangle, showing the topography typical of this area.

The southern part of the Mount Stuart quadrangle includes an area quite distinct in its topographic features from that described above. Here there is a transition into the type of topography characteristics of the Yakima region. While the streams may have canyons similar to those farther north, they are farther apart. The divides are broad and comparatively level topped. The valley of the Upper Yakima forms the dividing line between the two areas, and the surface geology is also quite different on the two sides of this valley, in the vicinity of Clealum. On the south the prominent escarpment of the Yakima basalt overlooks the river and on the north are the lower ridges of Eocene sandstone. However, the differences in topography are not wholly due to the geology, as will be shown in a later section of this paper.

YAKIMA REGION.

That part of Yakima County which lies adjacent to the course of the river of the same name possesses a topography that is unique. Its origin will be fully discussed in the following pages, so that only a brief description is necessary here. In its general features this topography is very simple. Long canoe-shaped valleys, with intervening ridges, form a quite constant succession with the general trend transverse to the course of Yakima River. Some of the valley floors reach the river level while others lie several hundred feet above the bottom of the river canyon. The ridges rise from 1,000 to 3,000 feet above the valleys, with fairly gentle slopes and even crests, except where interrupted by the deep water gaps of the river. The relation of these ridges and valleys to the river may be seen in the sketch map of Yakima Canyon (Pl. VI); and the topography of a typical portion of the region is given with more detail in Pl. V. Pl. II shows very well the character of Yakima Canyon where it cuts through Manastash Ridge.

This description of the topography would be incomplete without mention of the landslides that are common in central Washington, a topographic form fully described by Prof. I. C. Russell in several papers. The active canyon cutting and favoring geologic structure has caused this area to afford wonderful examples of landslide topography. One of the best of these is on the southern slope of Cleman Mountain, and is well represented on the physiographic map (Pl. V). These landslides vary in size from some to be measured by cubic miles of displaced rock to others involving less than an acre of surface. In age this range is scarcely less striking, certain landslides antedating the high terrace gravels deposited when glaciers occupied the Upper Yakima Valley, while other slides are of so recent origin that vegetation has not yet gained a foothold.

CASCADE LOWLAND.[a]

IDENTIFICATION.

As was noted in the discussion of the literature, Professor Russell finds in the plateau-like surface of the Cascade Mountains evidence of previous reduction of the region "to a plain, or an approximately plain, condition nearly at sea level." This was the "Cascade peneplain," the subsequent elevation of which resulted in the "Cascade plateau." In view, however, of the complete dissection of this plateau into a complex of sharp ridges and peaks, as described by Russell, it is evident that both plateau and peneplain are somewhat hypothetical. A general uniformity of altitude of the ridges and peaks of the central portion of the Cascades may be made out in certain districts, but so frequently are other peaks seen which rise above this level that this class of evidence taken alone is far from conclusive. Indeed, this is best appreciated by those who have been most earnest in their search for traces of the old peneplain. Furthermore, the date of the supposed planation has not hitherto been determined even approximately.

The identification of possible remnants of the old lowland, if such a lowland existed, becomes most essential to the investigation of the later history of the Cascade region. By reason of the aridity of its climate and consequent slight erosion the conditions in the area along the lower course of Yakima River are most favorable for the preservation of land forms. Erosive activity is mostly confined to the larger streams which head in areas to the north and west where the precipitation is greater. Under such conditions it appears quite possible for deformation to outstrip erosion, with the result that the relation between structure and topography becomes at once both close and obvious.

At first glance, the topography of this Yakima region is seen to be dependent upon structure. The ridges are anticlinal and the valleys synclinal. This relation necessarily involves a more or less perfect parallelism between the surface and the rock structure. The parallelism may or may not be easily observed, but the determination of the degree of this conformity between structure and surface becomes of the greatest importance.

The first hypothesis to suggest itself in the course of the field work in the northern part of the area here discussed was that the anticlinal and monoclinal ridges bounding the extensive Kittitas Valley were in a great measure pre-Ellensburg. This valley with its floor of Ellensburg sandstone, horizontal or only gently inclined upward at the borders, has the general features of a structural basin in which lacustrine sediments have been deposited. Such a view would involve an unconformity between the Miocene lava and the succeeding sediments, and the Ellensburg formation would be found to occur only in the synclinal basins where it had been deposited. Further study of the area, however, showed that the distribution of the Ellensburg formation is too general to permit of its being considered a local deposit of the character suggested.

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[a] Cascade is here used purely in a geographic sense. To express the period of development of this lowland, Mr. Willis's term "Methow" would be more exact, and its use becomes necessary in his more detailed discussion of the successive stages in the history of the Cascade Range.

The second explanation to be tested in the field was that the soft sandstones had been eroded from the crests and higher slopes of the anticlinal ridges, the Ellensburg thus being left only in the lower parts of the synclinal valleys. This apparently was the opinion held by Professor Russell in his reconnaissance of the Yakima region. On this supposition, it was not pre-Ellensburg but post-Ellensburg movement that uplifted the anticlinal ridges of the area. Subsequent to the warping of the surface of the Miocene sediments, erosion removed the softer beds from the ridges, which determined the general distribution of the Miocene rocks as now observed, the upfolded basalt forming the ridges, and the Ellensburg sandstone occurring in the valleys between. In this way there was a perfect conformity between surface and structure, although with a subsequent destruction of this original surface, except in the floors of some of the basins or valleys, where the whole thickness of the sedimentary formation may have been preserved. The level tops of the ridges, therefore, while not preserving the original surface, would be parallel to it and in a way represent it, since the sheets of resistant basalt parallel to the original surface have determined the present surface.

This second hypothesis also had to be abandoned because field evidence did not support it. The essential feature of conformity between surface and structure was found to be wanting, so that it became evident that the true explanation is less simple. Where the even surface is best preserved, on the level crests of the ridges and on the long, gentle, and smooth slopes along the flanks of the same ridges, it is apparent that this surface does not parallel the underlying rock structure. The dip of the rock and the inclination of the slope agree in direction but differ in amount. The rock dip commonly exceeds the slope, and higher beds occur in the valley than can be found on the ridges, and while such valleys may be unsymmetrical with regard to the slopes on either side, the rock folds are even less symmetrical.

Tracing the rock slopes of the valley sides upward until the even crests of the ridges are reached, lower sheets of the basalt are successively crossed, until it is evident that the crests of the anticlines have suffered considerable erosion, so that the highest beds are found in the synclinal valleys and the lowest on the crests of the anticlinical ridges. The result has been more than the erosion of the softer sandstone strata from the ridges and their preservation in the neighboring valleys. The surface is thus an erosion product and cuts across both the folded Yakima basalt and Ellensburg sandstone.

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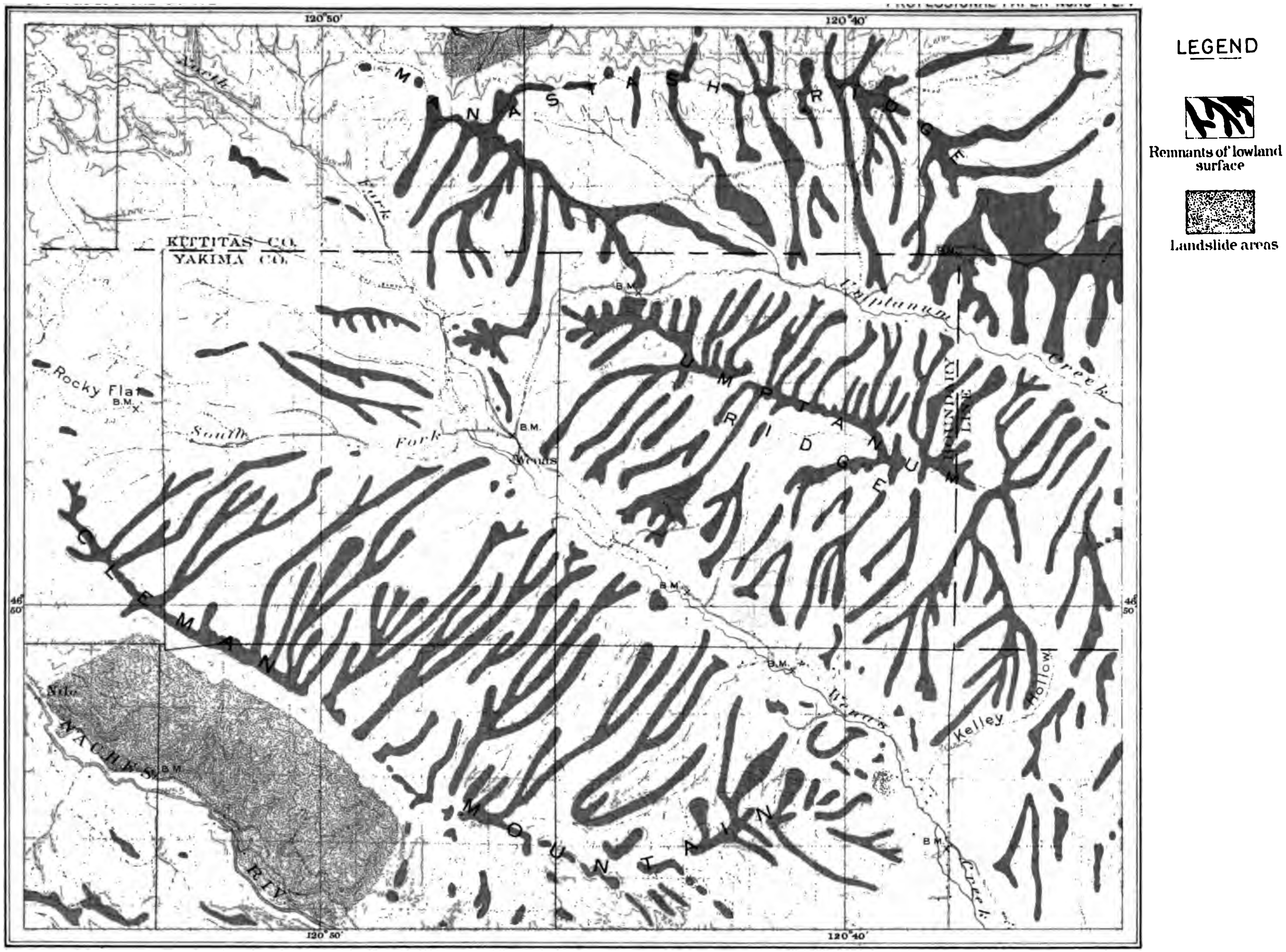
This beveling of rocks as widely different in their resistance to erosion as the hard, compact basalt which withstands the attacks of stream corrasion and the soft friable sandstone easily eroded even by the desert winds is especially noteworthy in connection with the present discussion. The absence of any scarp or other topographic form expressive of differential resistance of the two rocks indicates a long continuance of the erosive activities producing this surface. Such perfection of planation could not be expected much short of reduction to a baselevel, so that the natural deduction from these observed facts is the former presence of an essentially level lowland over the area. Therefore, the third hypothesis was adopted in the field, namely, the ridges and valleys of the Yakima region represent a warped lowland surface. The relation of this surface to the rock structure is not a simple one. The reduction of the area of previously folded rocks to a lowland caused any perfect conformity between the surface and the structure to be very exceptional, while on the other hand, the general or approximate parallelism between the two as observed at many points becomes explicable from the fact that the warping of the lowland surface was in the main along lines coincident with the axes of prelowland folding. This double deformation resulted in steeper dips for the rock strata, which were subjected to both movements, and more gentle inclination of surface slopes which have been affected only by the later warping.

DEVELOPMENT.

The extent of this Cascade lowland and the degree to which it was developed may next be considered. In the Yakima region exceptional conditions favor its preservation, and the recognition of this physiographic feature is easy. Detailed mapping reveals the fact that the Cascade lowland was, in this area at least, a comparatively perfect one. Remnants of the old lowland now uplifted on the flanks of the anticlinal ridges are seen to have a remarkably uniform surface. On the sketch map of a portion of the Ellensburg quadrangle (Pl. V) are indicated the portions of the old lowland surface that have escaped destruction by later erosion. In the field the evidence appears much less fragmentary than on the map. The narrow gulches that score the sides of the ridges are unsuspected when one looks along the slope. What is seen is a gently inclined featureless surface extending from the even crest of the ridge to the valley floor below, often without a perceptible break. This surface is commonly covered with basaltic débris, usually quite coarse, which has been derived from the basalt exposed in the immediate vicinity. On some very gentle slopes a thick deposit of fine silt is found. Whether or not this may represent a lowland deposit can not be definitely stated, but its present distribution is in part due to wind action.

On this planation surface it is often impossible to trace the contact between the



PHYSIOGRAPHIC SKETCH MAP OF A PORTION OF THE ELLENSBURG QUADRANGLE, WASHINGTON

two formations. The accompanying illustration (fig. 1) shows such a case, and is drawn from a photograph of the spur east of Kelly Hollow on the southern slope of Umptanum Ridge. This may be considered the type locality for the recognition of the lowland surface. The plateau is several hundred yards in width and over a mile in length, and preserves its even surface to the very brink of the steep-sided gulches that bound it on the east and west. The surface is thickly strewn with angular bowlders of basalt, and there is not the slightest indication of the contact between the Yakima basalt and the overlying Ellensburg sandstone. On either side, however, on the walls of the gulches the position of this contact can be accurately fixed and its dip seen to be 20°. Here, then, the planation was complete and the resultant lowland surface is perfectly preserved.

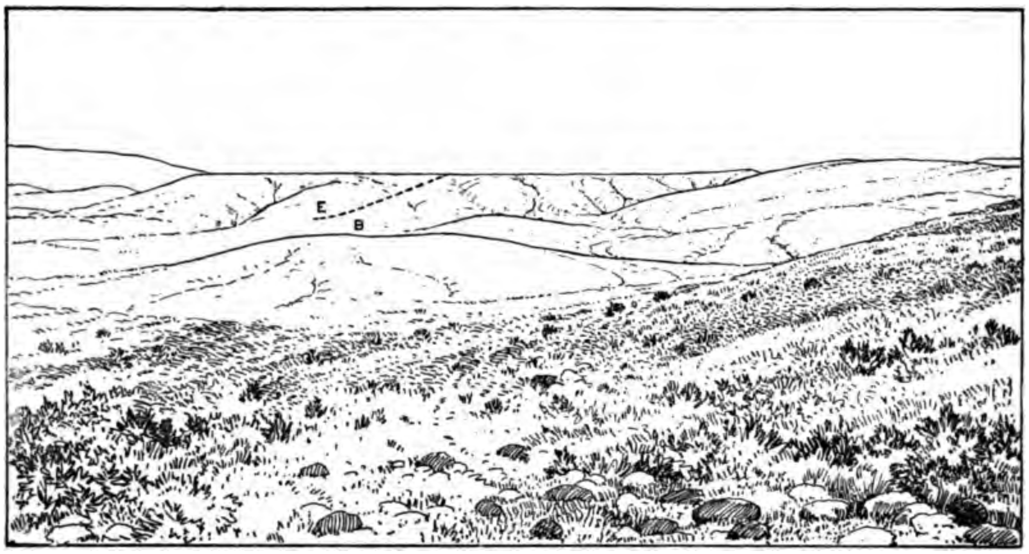


FIG. 1.—Contact of Ellensburg sandstone and Yakima basalt—E, Ellensburg; B, Basalt.

The profile of the deformed lowland, with the relation of this surface to the rock structure, is well shown in the section on Pl. VI. This section extends from Ellensburg to the vicinity of North Yakima, and while in a general way it is parallel to the accompanying map, it was made to follow as far as possible the unmodified spurs between the gulches that have been cut into the slopes. It represents, therefore, as well as a true section can, the lowland surface now warped to form the ridges and valleys of this area.

On the slopes of Manastash Ridge, Umptanum Ridge, Cleman Mountain, Cowiche Mountain, Selah Ridge, and Atanum or Yakima Ridge remnants of the Cascade lowland can be detected. Farther north, in the Kittitas Valley, the old surface may be recognized on the slopes of Table Mountain and of Lookout Peak, where the inclination of the surface is seen to be less than the rock dip, in the sloping surface of the even-topped terrace of Ellensburg sandstone along Yakima River, and in the flat-topped mesa of similar material near the Normal School Building in Ellensburg.

The identification of the old lowland surface becomes more difficult outside the area here described. Eastward, undoubtedly it can be traced to the plain of the Columbia, and to the northeast the even surface of Table Mountain appears to be continued in the even-crested but lower ridges just south of the mouth of Wenatchee River. Table Mountain thus serves to connect physiographically the Yakima region with the area described by Willis in the second part of this paper. North of Lookout Mountain, in the Mount Stuart quadrangle, as may have been inferred from the description of the topography, there are no traces of a peneplain surface. In the western portion of the Ellensburg quadrangle, where the ridges mentioned above unite to form a broad plateau, the distinction can not be made with certainty between the old surface and a possible later erosion feature, which may be determined by the gentle monoclinal structure of the basalt. Especially is this true on account of the absence of the Ellensburg sandstone and the consequent lack of the best criterion for the recognition of the old lowland surface.

The evidence of the reduction of a large area of folded Tertiary rocks to form the Cascade lowland appears conclusive. The date of the development of this lowland is fairly well determined, since folds involving late Miocene strata are truncated, while on the other hand the subsequent history of a large part of the region has been so eventful that the production of the lowland surface could not reasonably have been later than Pliocene. Previous to this Pliocene reduction, erosion does not appear to have ever produced anything like a peneplain in the northern Cascades, as far as its history has been determined. In view of the eventful character of the whole of the Tertiary, it is plain that the period of reduction to base-level can not be considered as including any large part of Tertiary time, as has been suggested by Russell. Uplifts or subsidences of the extent that are known to have occurred during Eocene and Miocene time in this area must be considered as inaugurating new topographic cycles. Furthermore, the land surface that was flooded by the basalt flows at the beginning of the Miocene possessed considerable relief. This pre-Miocene topography has been preserved in a large measure from later erosion by the basalt, and where the capping is partially eroded away and stream canyons are cut down into the underlying formations the contact shows very conclusively the character of the old surface. Such a locality is the valley of Taneum Creek, where it is at once seen that the prebasalt surface was such as to deserve to be termed rugged topography. It seems necessary, therefore, to restrict the period of the development of the Cascade lowland to the Pliocene.[a]

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[a] It is of interest to note that in the John Day Basin, Merriam finds evidence of the erosion of the upturned Miocene formations early in Pliocene time: Bull. Dept. Geol. Univ. California, Vol. II, No. 9, p. 311.

CASCADE PLATEAU.

CHARACTER OF THE UPLIFT.

Russell's term, "Cascade plateau," is used in this paper as a convenient designation for the uplifted lowland surface. The term is of value as expressive of the change in attitude and as descriptive of the mass from which the Cascade Range has been carved. It is not, however, to be inferred that a broad, unmodified table-land once existed where now there are rugged peaks and deep canyons. The uplift was not catastrophic but slow and gradual, and further knowledge of its character may be gained from the study of the Yakima region.

Here, as has been noted in the previous section, the uplift was effected with pronounced deformation along well-defined axes, producing parallel ridges. This evidence in the region where the upraised surface has been so preserved that definite conclusions are possible suggests that the uplift of the Cascade Mountains was not necessarily of a broad and general character, producing a dome with gentle slopes extending over thousands of square miles, but that the uplift was effected with similar local warping in other parts of the Cascades.

This may serve to explain the lack of uniformity in elevation of some of the higher peaks. Such cases are cited by Russell,[a] and he suggests four hypotheses to explain the greater prominence of the granite peaks, of which Mount Stuart is a type. The postpeneplain elevation of such masses is rejected on the ground that the structure antedates the period of reduction to base-level. Another hypothesis is that these high peaks represent monadnocks on the old lowland, and another that the higher peaks, being composed of the more resistant granitic rocks, more nearly preserve the original general surface level of the Cascade plateau, which was about 10,000 feet above sea level, while the peaks of softer rocks have suffered a general diminution in height. A fourth hypothesis "calls for local upheavals since the Cascade peneplain was raised into a plateau and subsequent to the initiation of the present master drainage lines,"[b] an upward movement which is thought possibly to be still in progress. This last hypothesis appears to Russell to best explain the observed facts, and a modification of this may be here suggested in light of the later observations in the Yakima region.

The uplift of the Cascade lowland to form the Cascade plateau on the present supposition was not a simple, broad, flat-topped, anticlinal uplift, but a deformation of more complex character. The Wenatchee uplift was not necessarily a local uplift subsequent to the main Cascade uplift, but rather a part of that uplift and contemporaneous with the localized deformation in the Yakima region. The Wenatchee Mountains are thus comparable to Manashtash and Umptanum ridges to the south, and may, indeed, form the higher part of a somewhat broader uplift, of which the Table Mountain-Lookout Peak ridge, 20 miles south of Mount Stuart, forms the lower flank. On the Wenatchee Mountains apparently no remnant of the old lowland surface remains, although such a surface is suggested by the level platform from which the upper 1,500 feet of Mount Stuart rises as a monadnock, but on Lookout Peak and Table Mountain such a surface can be detected extending down into the Kittitas Valley, as noted above. It must be kept in mind, however, that such an uplift in no sense explains the rock structure, which greatly antedates this surface deformation, but, like the cases cited in the Yakima region, the later uplift was apparently along an older structural axis, and it is only by detailed study of the basal contacts of the different Tertiary formations that the distinction can be made between Eocene deformation and the deformation which followed the post-Miocene reduction to a lowland.

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[a] Twentieth Ann. Rept U. S. Geol. Survey, pt. 2, pp. 139-142.

[b] Ibid., p. 141

VARYING DEGREE OF DISSECTION.

In the brief description of the topography of the Mount Stuart and Yakima regions the difference in type was pointed out. The variation in degree of dissection is at once apparent. This is in no sense due to differences in the formations eroded, but has its origin in climatic conditions. On the eastern flank of the range the precipitation is scanty and erosive processes correspondingly weak. Only the larger streams that head outside the arid belt accomplish much, so that deformation has been able to quite outstrip erosion, with the result that the warped lowland surface is preserved. On the higher slopes, especially nearer the crest of the range, the precipitation is greater, and active erosion has resulted in mature topography.

It is on account of this deep dissection that there is little remaining to more than suggest the Cascade plateau over large areas in the Cascade Mountains. Whether or not the acute peaks even approximate the old surface can not be determined, but it seems probable that in the higher portions of the range there has been a general diminution of height.

The cause for variation in degree of dissection other than that of a climatic nature is the length of the period during which erosion has been uninterrupted by crustal movement. In one area the topographic cycle may be continued from youth to old age, while in another region not far distant, in the same time, one cycle may be terminated and another inaugurated simply by a local uplift. The physiographic stages enumerated by Willis in his paper have not been differentiated in the foregoing description of the central Washington area. It is doubted, moreover, if such distinctions can be made generally throughout this area, by reason of its physiographic development differing from that of the region described in the following paper. This difference appears possible, and indeed probable, since in the case of gaps cut by Yakima River in ridges only a few miles apart the record in one case is shown to be that of an uninterrupted uplift of the ridge, while the compound form of the other gap shows a halt in the uplift sufficient for widening the canyon in its earlier portion.

A few points of connection between the two regions may be noted, however. The greater part of the Mount Stuart and Ellensburg quadrangles lies outside the limit of glaciation, and therefore direct reference of the date of topographic features to a glacial episode becomes difficult. The period of development of the Cascade lowland as described for the Yakima region of course corresponds to the Methow stage of Willis. The Entiat stage is poorly represented in the Mount Stuart quadrangle, and the only traces of topography antedating the present are found in the old valley of Camas Land and in several small areas now capped by rhyolitic lava, the pre-lava surface plainly possessing only moderate relief. Elsewhere in the northern half of this quadrangle dissection appears to have proceeded so far as to destroy all evidences of an earlier stage, while in the Yakima region these later stages have not been separated, the uplifted Methow topography having suffered extremely little modification. Since the physiographic development is the result of the interplay of earth forces and atmospheric agencies, it is evident both must remain the same throughout a region to result in the same succession of physiographic stages. Climatic differences appear to account for much of the topographic diversity, but the structural history is no less important. It would seem futile, therefore, to expect uniformity in the physiographic record over wide areas in a province like the northern Cascades if the writer is correct in his belief that the uplift of the range has been complex rather than simple. However, it is no less evident that the more complete record that can be deciphered for the one area is of material value in the understanding of the other area.

There is good reason to expect confirmation of the views here expressed in the course of future work. Already the writer has detected remnants of the uplifted lowland surface in higher portions of the Cascades. The Cascade plateau was also found to be exceptionally well represented immediately north of Mount Baker, near the international boundary. Here there is not only a marked uniformity in the elevation of the ridges, but their crests are broad and even. Such topographic characters belong to an older topography, and it is believed therefore that these features in reality mark the preservation of the lowland surface now uplifted to form the plateau with an altitude of over 5,000 feet. This plateau is incised by the deep canyons of Nooksak River and its tributaries, while upon it rests the volcanic cone of Baker. West of this region, toward the crest of the Cascades, the plateau character is lost and the more complete dissection makes the topography one characterized by the most acute peaks and rugged mountain masses. In this higher portion of the uplift the attack by erosive agencies has plainly been much more severe, and erosion has outbalanced deformation with the resulting destruction of the plateau type of surface.

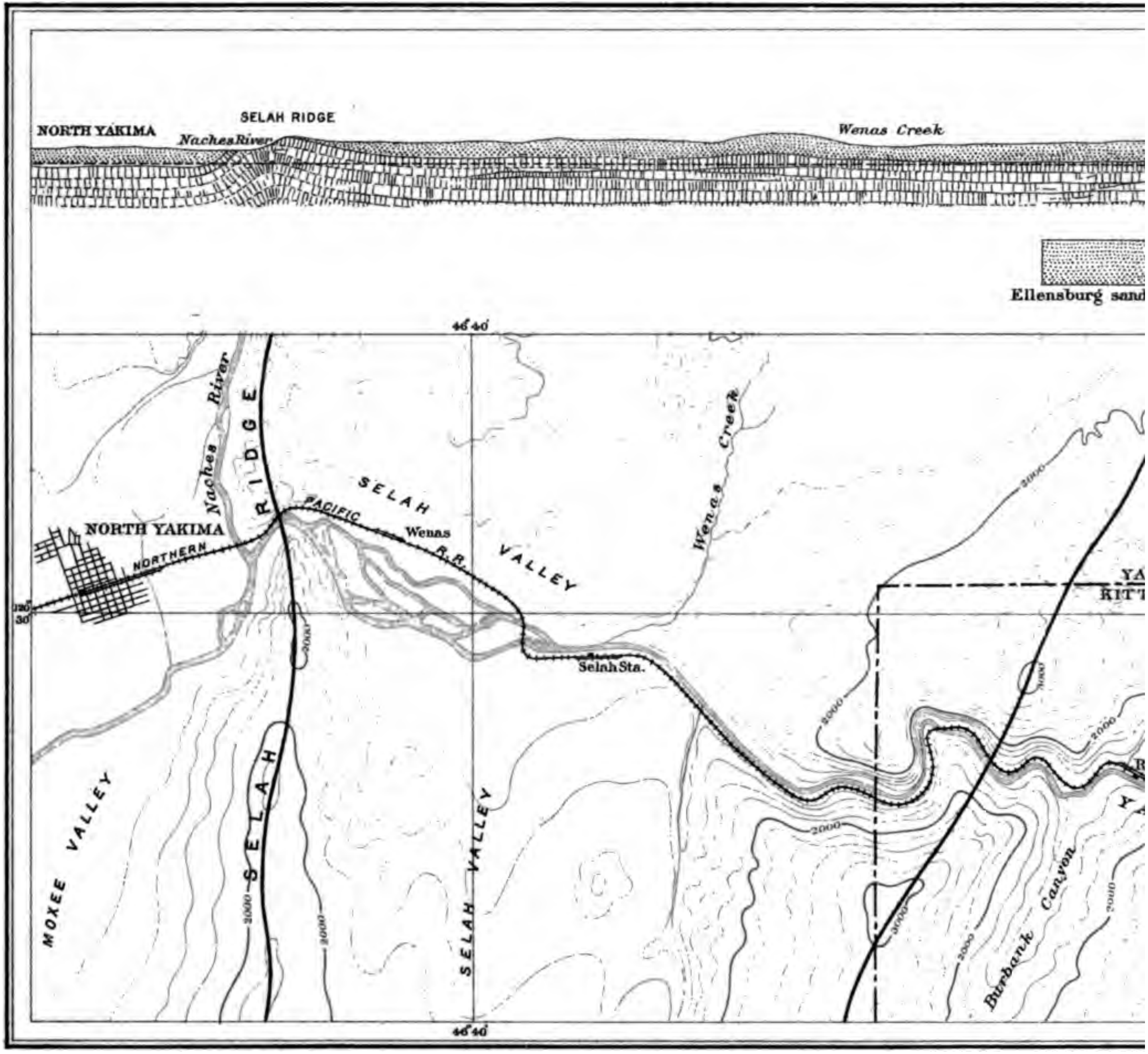
RIVER HISTORY.

In the higher parts of the Cascade Mountains it will probably be found that the only line of evidence bearing upon these physiographic problems is that furnished by the streams. The antecedent character of such streams as the Icicle, which cuts across the granite mass of the Wenatchee Mountains, has been recognized by Russell, and furnishes additional proof of the existence of the Cascade lowland. In considering the history of such streams and their relations to the rock formation across which they have cut their canyons it is most important that a sharp distinction be made between the rock structure and the surface warping. The former is the result of successive epochs of dynamic action preceding the Pliocene lowland reduction, while the latter comprises the elevation of the Cascade lowland to form the Cascade plateau or the uplift of the Cascade Mountains.

In the Yakima region where the lowland surface is best preserved the history of Yakima River, as it can be traced out, corroborates the physiography as stated in the earlier section of this paper. The antecedent character of this river is at once apparent, and, as noted in the review of the literature, Russell was the first to call attention to this important feature. As can be seen from examination of Pls. II and VI, the Yakima crosses the high ridges in a deep canyon in which the original meanders of the river are strikingly preserved. The course of the river antedates the uplift of these ridges, and the warping of the lowland surface must have been effected at a rate that permitted the Yakima to maintain its course without change. That there was no damming sufficient to cause the stream to seek a new channel is shown very conclusively in the vicinity of North Yakima. The river leaves the broad transverse valley in which that city is situated by cutting through Atanum Ridge at Union Gap, which is nearly a thousand feet deep. Five miles east this ridge has a low saddle, purely structural in origin, which affords an easy pass less than 200 feet above the valley floor. Here, had there been any ponding of the Yakima waters during the uplift of the ridge, the river would surely have discovered the lowest point in the rim of the basin; but there is no trace of stream occupation of the pass. At other points where the Yakima cuts through other ridges the relations are hardly less convincing, since often the water gap interrupts the ridge in its highest part.

The surface upon which this course of Yakima River was established plainly must have been the Cascade lowland. The independence which this course shows of the hard and soft rocks which made up that lowland points to the development of the meanders on a surface on which there had been a perfect reduction to base-level.

U. S. GEOLOGICAL SURVEY



SKETCH MAP OF THE YAKIMA CANY

WITH PARALLEL GEOLOGIC SECTION, SHOW

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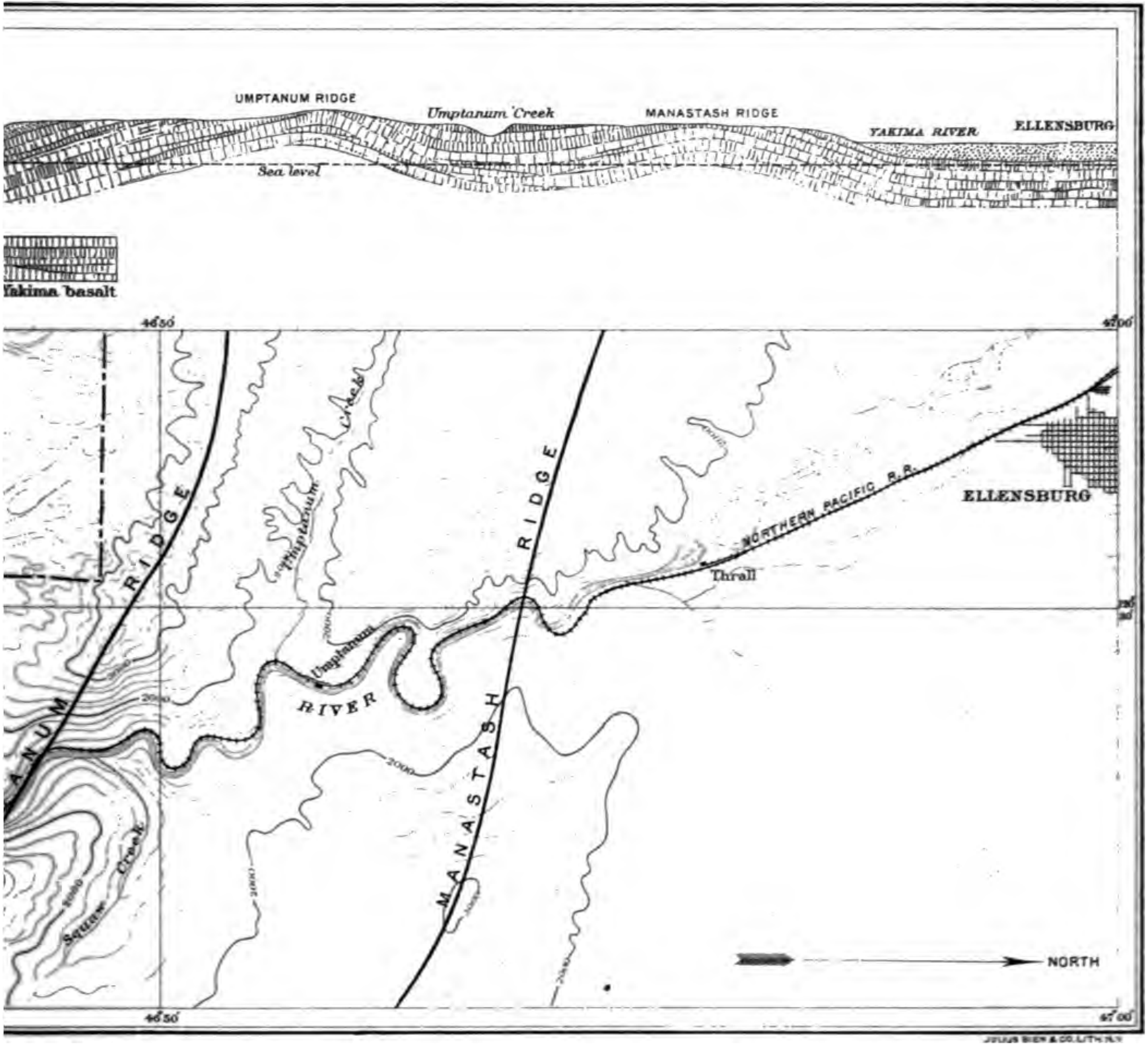


ING POSITION OF ANTICLINAL AXES

ION OF WARPED SURFACE TO STRUCTURE

MITH

3 4 5 miles

0 feet

Furthermore, the manner in which the lowland surface cuts across folds involving the Miocene sandstone indicates that the course of the Yakima was not determined, at this time at least, by the slope of the uplifted lake bottom, as suggested by Russell. Here, again, the later warping must be distinguished from the earlier folding of the rocks.

Naches River, the most important tributary of the Yakima, is plainly also of antecedent character, since it has cut diagonally across one of the anticlinal ridges, uniting with the main river near the axis of the ridge (Pl. VI). The smaller tributaries of the Yakima in this region appear to be generally synclinal in position and also consequent upon the warping of the lowland. This statement, however, needs modification, since in the cases of Wenas and Selah creeks portions of the streams cut across minor ridges. Selah Creek also flows along the north side of Selah Valley in a canyon the brink of which is above and over a mile distant from the axis or lowest part of the valley. Such a relation may be taken as showing that the course of the stream is antecedent to only a portion of the warping of the lowland, the axis of that deformation having shifted southward. Wenas Creek is peculiar in that while it flows along the rather broad valley between Umptanum Ridge and Cleman Mountain and may be considered a synclinal stream, its shallow canyon is cut along the axis of a low anticline. This fold shows both in the rocks, the basalt appearing in the canyon, and in the deformation of the surface. The geologic and topographic relations of the Wenas Valley can be seen on the map of this area (Pl. IV). Back from the creek on either side is a parallel valley across which the seasonal streams flow before joining the creek. The old lowland surface can be traced from the slope of the ridge across the back valley and up on the flat-topped hills overlooking the main creek, and the fact that basalt bowlders cover these hilltops where the underlying rock is sandstone shows that this is the lowland surface. At one place the back valley has so level a floor that a stream coming down from the ridge sometimes divides on its alluvial fan and flows out to the creek through two separate canyons. The explanation of these relations that presented itself in the field was that Wenas Creek was at first a synclinal stream in the valley between the two ridges, but by a later uplift of the low ridge along the center of this valley the creek cut down through the sandstone into the basalt beneath. There is evidence, too, that this later warping followed a structural line marked out at the time of the prelowland folding. The uplift of this medial ridge, a movement not exceeding 300 feet, was so gradual that not only did the main creek maintain its course but the tributaries suffered no changes, but crossed the unaffected back valley and cut steep-sided gulches through the uplifted ridge. A simultaneous and indeed connected uplift also occurred a few miles up the valley, where the two northern branches of the Wenas cut across an arch of basalt. The structure here can be seen perfectly in the canyons, and the flat crest of the ridge well expresses the lowland surfaces; and here again the absence of conformity between surface and structure is noticeable. This history of Wenas Creek is simply an incident, of little importance except as it may show that the warping of the Cascade lowland was not a simple, uninterrupted movement, in some localities at least.

An interesting problem in connection with the history of the Cascade Range will be the identification of the system of antecedent drainage of which Columbia, Yakima, and Wenatchee rivers appear to be important parts. It will be at once noticed that these master streams are in no sense consequent upon the broad Cascade plateau with its north-south trend, as described by Russell, nor altogether upon such minor uplifts as have been thus far recognized. These rivers are the streams that controlled and effected the reduction of the post-Miocene land surface to a peneplain, and the study of this drainage system may yield some data bearing upon the degree to which the planation was carried and upon the position of monadnocks and important divides. The extent to which it is justifiable to apply this hypothesis of the deformation of the old lowland surface into local domes or ridges, features measuring a few miles in shorter diameter, rather than into a broad plateau uplift measuring hundreds of miles in extent, can then be better discussed.

PHYSIOGRAPHY OF THE SNOQUALMIE QUADRANGLE.

Since writing the foregoing portion of this paper the author has extended the geologic mapping westward from the Mount Stuart area. The Snoqualmie quadrangle, which was surveyed in 1902, lies within the heart of the Cascade Range, and includes about 50 miles of the main divide between the Puget Sound drainage and the streams tributary to the Columbia. Such a region appears to furnish an opportunity for testing the wider application of the conclusions reached in the adjacent area. In the Ellensburg quadrangle erosion has been insufficient to destroy the traces of the Pliocene peneplain, now warped into the ridges described in the preceding pages. In the Snoqualmie quadrangle land sculpture has plainly reached a stage in which no traces of such a peneplain can be recognized. The topographic cycle is nearing maturity, and while the problem of interpreting the physiography is more difficult, it becomes interesting to make the test and to attempt to determine for this portion of the range the type of uplift which inaugurated the present cycle of erosive activity.

As a preliminary to this, it is helpful to review certain of the general principles of land sculpture as first and most clearly defined by Powell and Gilbert. These will be briefly stated in so far as they apply to the question in hand, which is, What was the character of uplift of this central portion of the Cascade Range? Such general principles may be stated thus:

Degradation is controlled by declivity, rock structure, and climate. As will be seen below, the second and third factors may be omitted in the present consideration. While of great importance, they are essentially without value as criteria in this instance. Degradation, including erosion, sapping, and corrasion, as well as transportation, increases with declivity.

The work of ordinary degradation may be greatly augmented by glaciation, which, as will be noted later, was not universal in this area, hence glaciation has value for the purpose of this discussion.

In the case of the simple uplift of a broad arch, there would result a flat top and steeper flanks. On the steeper flanks the greater declivity would determine the locus of the more effective degradation. With consequent streams, therefore, the maximum rate of degradation would obtain along the flanks of the arch, and at any stage there would result an axial ridge with axial peaks as the highest portion of the uplifted area. This result may be stated differently, following Gilbert: There would be a persistence of divide, since at first it was the divide because an eminence, and later an eminence because the divide.

If the elevation was so slow in its first stages as to enable degradation to keep the axial region practically reduced, the resultant form would have a plateau character, as Powell has pointed out in the case of the western portion of the Uinta uplift. There, however, the axial region is higher, although its prominence is inconsiderable when compared with the whole amount of degradation.

With antecedent streams there is not the same persistence of divides, but rather a change due to the tendency of the streams to become more and more consequent. As developed by Campbell, the law of this migration of divides is that the divide tends to migrate toward an axis of uplift and away from one of subsidence. Thus it follows that in the case of a warped peneplain the antecedent drainage would tend to adjust itself to the warping and the streams would come to occupy the axes of relative depression with divides located upon the axes of elevation. In the case where the axis of depression shows changes in direction of pitch there would also be the tendency for the point on this axis, marked by divergence of pitch, to become also a divide.

Now, turning to the Snoqualmie area, certain facts of observation may be stated, as they apply to the problem under discussion.

The main divide of the Cascade Range within this quadrangle is wholly upon Miocene rocks, with the exception of 2 miles, where it is close to the contact of the Miocene with the Eocene. The highest peak on this divide, which has an altitude of 7,512 feet, and the lower portion of the divide for a considerable distance—with an altitude of 3,500 to 4,500 feet—are composed of Miocene volcanic rock with essentially the same physical characters. For this reason it appears evident that, as was stated above, rock character is not at all a controlling factor.

Climatic conditions are more or less uniform over this area, and any differences are dependent upon relative altitude, which in turn is involved in the question of relative uplift which is being discussed. Climate must therefore be left out of the discussion, and it is plain also that it would not have any important bearing on the final decision.

In the Lower Yakima region, where the river was antecedent, it was shown that the rate of uplift of the transverse ridges was not essentially more rapid than the rate of corrasion. The uplift, however, was greatly in excess of ordinary erosion, since many remnants of the uplifted surface remain. In the central region Yakima River carries its low-grade valley well back toward its head, so that the rate of uplift here has not been much greater than the maximum rate of corrasion. No actual remnants of the old surface, however, are known in this mountainous region, so that while degradation has far from kept pace with uplift, it has been efficient enough to produce a topography that has many characteristics of maturity. The question of the antecedent or consequent character of the drainage again depends upon the main question.

As can be seen on the accompanying map of the Snoqualmie quadrangle (Pl. VII), in which only the 500-foot contours above 5,000 feet are shown, the trend of the higher portions of the area is slightly north of west. The main divide has a general trend of a few degrees east of north, so that the difference in trend is approximately 90 degrees. Further, it will be seen that the high peaks on the divide are where it is crossed by these east-west heights.

The streams in the vicinity of the outlying heights are fully as efficient as those near the main divide, and in many cases possess the advantage of shorter courses and steeper gradients.

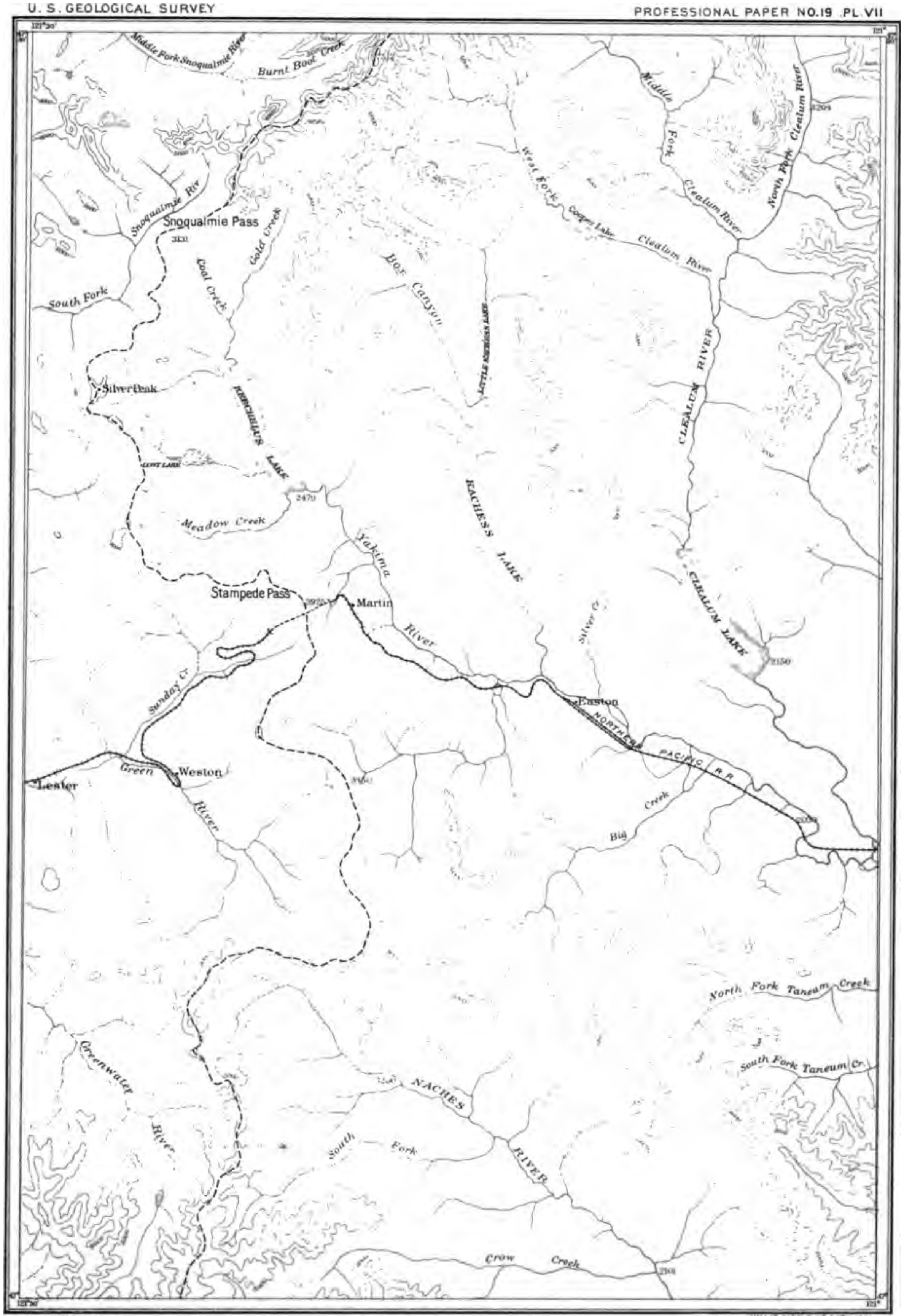
The thick mantle of soil which is of common occurrence in the lower divide region must be taken as strong evidence of the inefficiency of transportation here as compared with the higher country.

Glacial erosion has been an important factor in the northern area, characterized by a greater topographic prominence, while glaciation has been wanting in the lower parts of the main divide.

As the third part of this section, the foregoing general principles and particular facts may be brought together and certain conclusions deduced. This process will constitute the wider application of the hypothesis based upon the work in the Ellensburg quadrangle. The deductions are as follows:

(*a*) Whatever the rate of uplift, the axial region should exhibit some topographic prominence. If uplift has outstripped degradation, as is the case in this area, the axial ridge must be a distinctive feature.

In fact, the main divide in the Snoqualmie quadrangle fails to show any such prominence, except as was noted above. Therefore it is not the axial region.



Topography from
United States Geological Survey
topographic map

JULIUS BIEN & CO. LITH. N.Y.

MAP OF THE SNOQUALMIE QUADRANGLE, WASHINGTON

CONTOURS OF 5000 FEET AND ABOVE, WITH 500-FOOT INTERVAL, ARE GIVEN TO SHOW DISTRIBUTION OF HEIGHTS WITH REFERENCE TO MAIN DIVIDE OF CASCADE RANGE

Scale

1 0 1 2 3 4 5 6 7 miles

1 0 1 2 3 4 5 6 7 kilometers

Datum is mean sea level

(*b*) Uniformity in present altitude of neighboring heights is suggestive of preexistent uniformity, even if not exactly indicative of the actual position of the older surface. A line connecting closely adjacent heights, even although these are separated by canyons representing the work of efficient stream corrasion, is expressive of the position of an axis of uplift.

In the Snoqualmie quadrangle the position of three such axes of uplift may be approximately determined. The southernmost of these extends beyond the boundaries of this quadrangle, both east and west from the divide. Next, northward, is the high ridge between Naches and Yakima rivers, which is topographically and, in part at least, structurally the continuation of Manastash and Umptanum ridges to the southeast, which are known to represent upwarps of the old peneplain. Likewise, the third line of heights along the northern edge of the Snoqualmie quadrangle connects with the prominent Mount Stuart mass which constitutes the axial portion of the supposed Wenatchee upwarp of the lowland surface. These three lines of heights, which thus possess marked topographic prominence, are believed to indicate the position of three upwarps of the lowland surface.

How nearly the present surface on these heights represents the old surface thus uplifted can not be so definitely stated. On the highest portions of the Naches-Yakima ridge the level tops are strongly suggestive of the old surface. The uniformity in the present altitudes is a striking feature of the northwestern portion of the area, as illustrated by Mr. Willis on Pl. IX, and this uniformity may reasonably be considered the result of a general reduction of these tops, which has been relatively slight in amount.

(*c*) In whatever degree the system of divides fails to accord with the deformation, the drainage system shows similar lack of consequence. Streams cutting across lines of uplift must be antecedent, in part at least, and, with antecedent streams, the divides may be in process of migration.

In the Snoqualmie quadrangle the main divide has been shown to be not coincident with the axis of most marked surface deformation. Near the northern edge of the quadrangle the divide makes a sharp turn to the east and continues this northeastern trend for several miles beyond the boundary of the area described here. This trend coincides more nearly with the axis of uplift indicated by the east-west line of heights.

In the lower country of the Ellensburg quadrangle Yakima River is known to be antecedent to the warping of the peneplain and Naches River to be antecedent in a portion of its course and consequent in other portions. The history of the Puget Sound streams has not been studied.

It appears evident, then, that these two master streams may also have a mixed character in the Snoqualmie quadrangle. The Naches system is for the most part consequent upon the two upwarps shown by the elevated ridges, and a relatively high portion of the divide is at its head where the downwarp between these two upwarps dies out. The most important tributary of the Yakima, Clealum River, appears to head somewhat north of the northern axis of uplift and is in that case antecedent. The Upper Yakima itself, however, plainly occupies an area of relative depression and receives consequent streams from the slopes of the upwarps to the north and south. There is some evidence, however, of partial inconsequence, but the position of the main divide which parallels for about 10 miles the upper course of Yakima River appears to be in part determined by the cross axis from which this downwarp pitches.

A drainage system consequent upon complex warping of this character is thus less symmetrical than one consequent upon a broad arch. The partial inconsequence expresses simply the effect of the antecedent character of these streams which was partially preserved wherever the rate of uplift or warping failed to be the determining factor. In general, however, it is quite possible that much of the antecedent drainage may have been consequent upon prepeneplain structure, which was paralleled by this later warping, so that in the following cycle the antecedent streams have maintained their courses which may also appear to be consequent upon the warping.

The degree of agreement of the drainage with the surface deformation may furnish data for the separation of the uplift of the Cascade Range into distinct stages, as well as a more exact differentiation of the upwarps that constitute this uplift.

(*d*) The ultimate deduction is that, whatever the relative proportion of antecedent and consequent character in the drainage system, the main divide for the greater portion of its length in this area neither coincides with nor parallels the axes of most marked deformation of the preexistent surface. The uplift to which the Cascade Range owes its origin was not simple in type, but complex, and within this area can be resolved into three well-defined upwarps, which, moreover, are transverse to the main trend or major axis of the range considered over the larger area to the north.

RÉSUMÉ.

In the central Washington area detailed mapping has given data for the recognition of a lowland surface, the fixing of the age of its development as Pliocene, the suggestion of the drainage system which controlled that reduction to a peneplain, and the determination of the kind of deformation to which this lowland surface was later subjected. Such evidence has its bearing upon the broad problem of the origin of the great plain of the Columbia and the Cascade Range. To the east, deformation of the lowland has been less marked, while on the other side erosion has largely destroyed the uplifted peneplain. Future investigation may be productive of corroborative evidence over a larger area. The evidence in hand, however, is believed to be sufficient to prove the youth of the Cascade Range and to suggest that the general type of its uplift may have been complex rather than simple.

The data furnished by this study of the geology and physiography of central Washington may also have a bearing upon broader problems. The eventful character of Tertiary history in this province is noteworthy, as showing the rapidity with which geologic processes may accomplish their work. The Eocene section measures not less than 10,000 feet in thickness and is divisible into four distinct formations, separable both by physical breaks and by differences in fossil floras. In the Neocene period not only was there the great volcanic activity and the later deposition of the Ellensburg sediments, but also widespread deformation and the production of an extensive peneplain were effected.

Another feature of general interest is the deformation this peneplain has subsequently suffered. The evidence is believed to be conclusive that the old lowland surface has been warped so as to form anticlinal mountain ridges and synclinal valleys. Elsewhere no such striking instance of peneplain modification has been described, and this unique character of the area is doubtless to be attributed in part to the structural characteristics of the jointed sheets of basalt involved in this deformation. Connected with this warping of the peneplain is the antecedent character of Yakima River, which serves as an exceptionally fine example of that type of stream in that it has maintained its course across not only one but several uplifted ridges.

A third principle that demands recognition is the importance of separating the results of two or more distinct periods of deformation. In this way only can there be any true interpretation of structure in cases, such as the Yakima region, where the later movement largely followed the axes of earlier folding. Subsequent work in the Cascade Range has strengthened the belief that such persistence of structural lines through successive epochs of deformation is not at all exceptional and must not be overlooked.

The results of this physiographic study promise to greatly facilitate future work in the northern Cascades, but they have also been presented here with the belief that they contribute somewhat to our understanding of peneplains and their subsequent modification, with the resulting difficulties attending their recognition and identification.

CONTRIBUTIONS TO THE GEOLOGY OF WASHINGTON

PHYSIOGRAPHY AND DEFORMATION OF THE WENATCHEE-CHELAN DISTRICT, CASCADE RANGE

BY

BAILEY WILLIS

CONTENTS.

Page.
Introduction 47
Physiography 49
  Descriptive analysis 49
    Columbia Gorge, Wenatchee to Chelan 49
      Columbia Canyon 49
      Chelan Butte 50
      The eastern bank 50
    Badger Mountain and Waterville plateau 51
    Tributaries of the Columbia 53
      Wenatchee Valley 53
      Entiat Valley 55
      Navarre Coulee and Knapp Coulee 56
      Lake Chelan 58
    Entiat Mountains 64
    Chelan Mountains 65
    Methow Mountains 66
  Synthetic discussion 68
    General statement 68
    Methow stage 70
      Conditions of development 70
      Criteria of recognition 71
      Distribution and character of residuals 72
    Entiat stage 75
      Physiographic relations 75
      Distribution and character of residuals 76
      Degree of Entiat relief 77
      Glaciated aspects of Entiat heights 78
      Maturity of Entiat topography 78
      Entiat features in arid areas 78
    Twisp stage 80
      Characteristic features 80
      Development of topographic forms 80
    Chelan stage 81
      Character of the record 81
      The basin of Lake Chelan 81

Page.
Deformation 83
        Criteria 83
        Fundamental propositions 84
    Cascade uplift 85
        Height and extent 85
        Limits of Cascade upwarp 85
      Marginal flexures 86
        Methow downwarp 86
        Methow upwarp 88
        Chelan Butte upwarp 89
        Waterville downwarp 90
        Badger Mountain upwarp 90
        Wenatchee downwarp and upwarp 91
  Episodes of deformation 91
    Pre-Tertiary deformation 91
    Tertiary and post-Tertiary deformation 92
  Causes of deformation 92
    Direction of stress 92
    Dimensions of the Cascade block 95
    Uplift by horizontal compression 95

ILLUSTRATIONS.

Page.

PLATE VIII. Map of Wenatchee-Chelan district, Cascade Range 48
IX. View of the high Cascades from head of Gold Creek, showing the uniformity of altitudes 50
X. View of the high Cascades from near Cascade Pass, showing the uniformity of altitudes 54
XI. View of Navarre Coulee 56
XII. Chelan Butte from the north shore of Lake Chelan 60
XIII. The Narrows of Lake Chelan 62
XIV. View from Chelan Butte, looking southwest down the Columbia Valley 64
XV. View from Chelan Butte, looking northwest over lower Lake Chelan to Stormy Mountain and Navarre Peaks 66
XVI. Physiographic map of the southern half of the Chelan quadrangle 72
XVII. Physiographic map of the northern half of the Chelan quadrangle 74
XVIII. Physiographic map of the southern half of the Methow quadrangle 76
XIX. Physiographic profiles in the Wenatchee-Chelan district 78
XX. Views near Cascade Pass: *A*, The southern slope of Boston Mountain, showing inclined joint planes; *B*, The pinnacles southwest of the pass, showing vertical jointing 94
FIG. 2. Diagram of a block 96
3. Diagrammatic cross section of a deformed mass 97

PHYSIOGRAPHY AND DEFORMATION OF THE WENATCHEE-CHELAN DISTRICT, CASCADE RANGE.

By BAILEY WILLIS.

INTRODUCTION.

The following article is based on observations made during several excursions in the Cascade Mountains from 1895 to 1900, inclusive, and upon discussions with Messrs. I. C. Russell and George Otis Smith, to both of whom the writer is much indebted. When engaged in exploration in the same province, between 1881 and 1884, the writer took little note of the physiographic aspects as such; to him they were then scenic aspects only, and impressive grandeur was the dominant idea they left. But upon returning in 1895, after eleven years spent in the Appalachians, the case was different. Association with Gilbert, Davis, Hayes, and Campbell in the discussion of physiographic relations of the eastern region prepared the observer to see the less evident, but not less definite, facts of the western province.

In 1895 the writer traversed the western slope of the Cascade Range from Mount Rainier to Skagit River, visiting especially Snoqualmie Pass and Monte Cristo. At the former place the diversion of Snoqualmie River by a moraine dam is a conspicuous fact. The former eastern course leads by a wide valley to Lake Keechelus, but the diverted stream is now cutting a precipitous canyon in the western slope. The discovery of fossil leaves, classed as Miocene by Knowlton, in graphitic slates in the crest of the pass suggested the post-Miocene uplift of the range. Near Monte Cristo wide general views were obtained, which swept the sky line from southeast by south and west to northwest, and it was apparent that many jagged peaks rose approximately to uniform altitudes, which might reach or fall little short of an ancient plain. Stratigraphic studies of the Puget group of Eocene and Miocene strata led the writer tentatively to assign this hypothetical plain to a late Miocene date, and to place among the latest events of the Miocene epoch the uplift by which the old lowland was raised to a position at or above the summits of the Cascades.

To test the validity of these inferences, during succeeding years the heights and slopes of the range were viewed from many points, and the intersecting lines of sight, leaping from peak to peak at nearly uniform altitudes, were thought to define clearly the general attitude of the ancient plain. Among the panoramic views upon which this hypothetical reconstruction of a vanished surface was based may be mentioned that from the eastern side of Mount Rainier, at 7,500 to 10,000 feet above sea, looking east and north; that from a spur (6,000 feet) of Huckleberry Peak at the head of Gold Creek in the northeastern corner of the Snoqualmie quadrangle, tracing the sky line throughout the entire circle except from northwest to north; that from Stormy Mountain (7,219 feet) in the Chelan Mountains in the western quarter of the Chelan quadrangle; and that from Boston Mountain (8,300 feet) north of Cascade Pass at the head of Stehekin Valley.

In the meantime, in 1897–98, Russell reached the conclusions expressed in a preliminary paper on the geology of the Cascade Mountains in northern Washington[a] in the following terms:

> "After the time of long-continued erosion referred to above, when the Cascade region in northern Washington was reduced to a peneplain, there came a time of elevation, when the peneplain, or a very large portion of it, was bodily raised some 7,500 feet at least, and thus became a plateau. In a broad view of the region this Cascade plateau may be considered as of the nature of a broad, flat-topped anticline, or, as Dana would probably have called it, a geanticline. The rocks composing this uplifted region had previously been folded, but we are justified in assuming, on what may be said to be general principles, that renewed movements occurred along these old structural lines. The main change was a general rise of a region of some 10,000 or 15,000 square miles. The total area affected was much greater than this, as the Cascade plateau extends both north and south of the field under discussion.
>
> "One of the most remarkable features in the relief of the Cascade plateau is the seeming nearly level character of its original surface. The uprising was effected without pronounced tilting. Perhaps, when our knowledge is more extended, it will be found that this conclusion is too hasty, but at present, from a study of the distribution of the rivers, as well as of the heights of the peaks left by erosion, it does not seem that the plateau had a decided, if any, inclination toward either the east or the west. This is the most marked difference between the Cascade plateau in northern Washington and the Sierra Nevada. The Sierra Nevada, as we now find it, is the result of the erosion of a tilted plateau, bordered on the east, from Owens Lake to Mono Lake at least, by a great belt of branching fractures and faults. No such belt of fractures and displacements parallel with either border of the Cascade plateau is known. The evidence is that the rise from each side of the plateau to its nearly flat summit portion is gradual."

Among the services rendered the writer by George Otis Smith was that of well-maintained skepticism in regard to recognition of an ancient plain over the Cascades.

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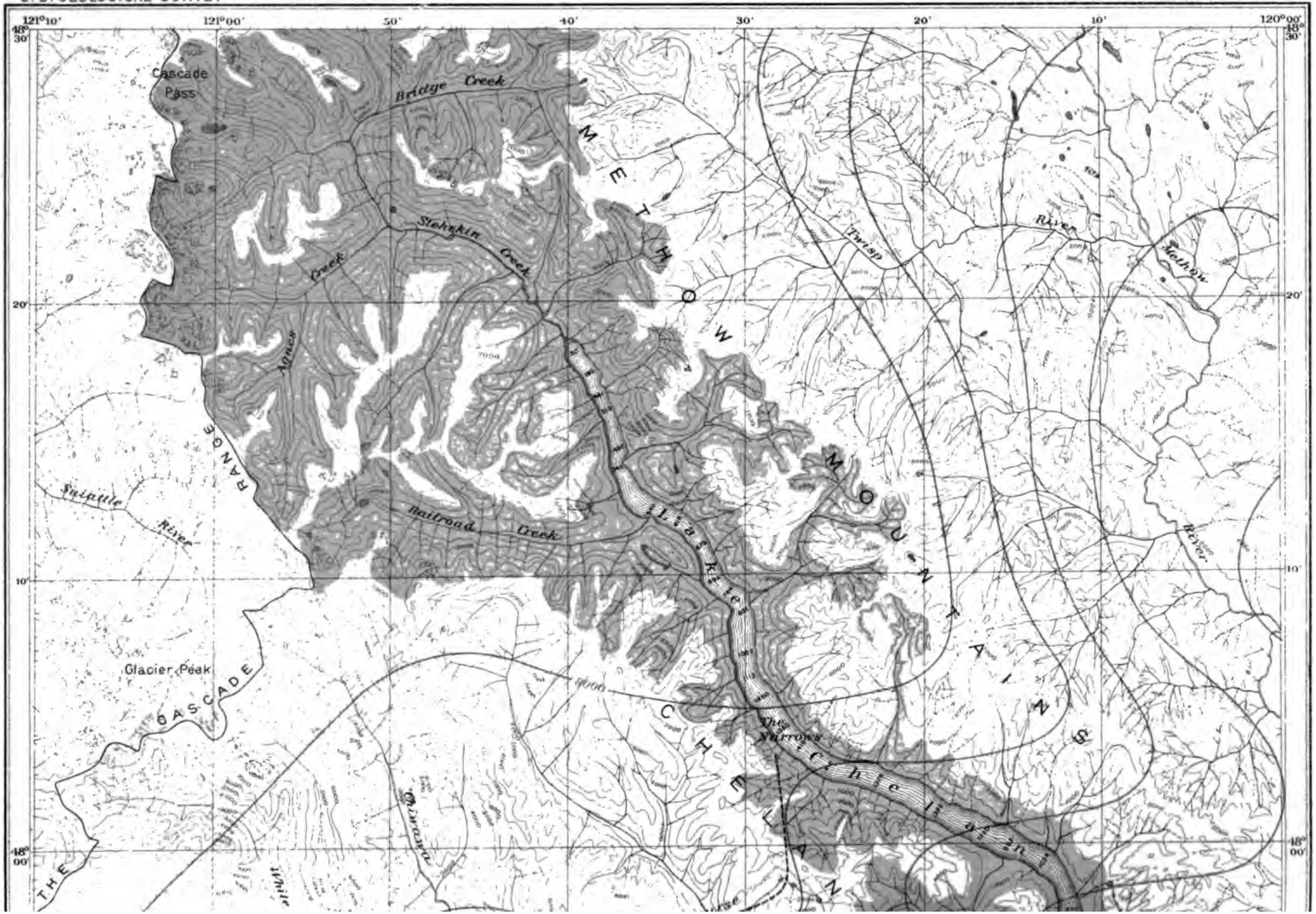
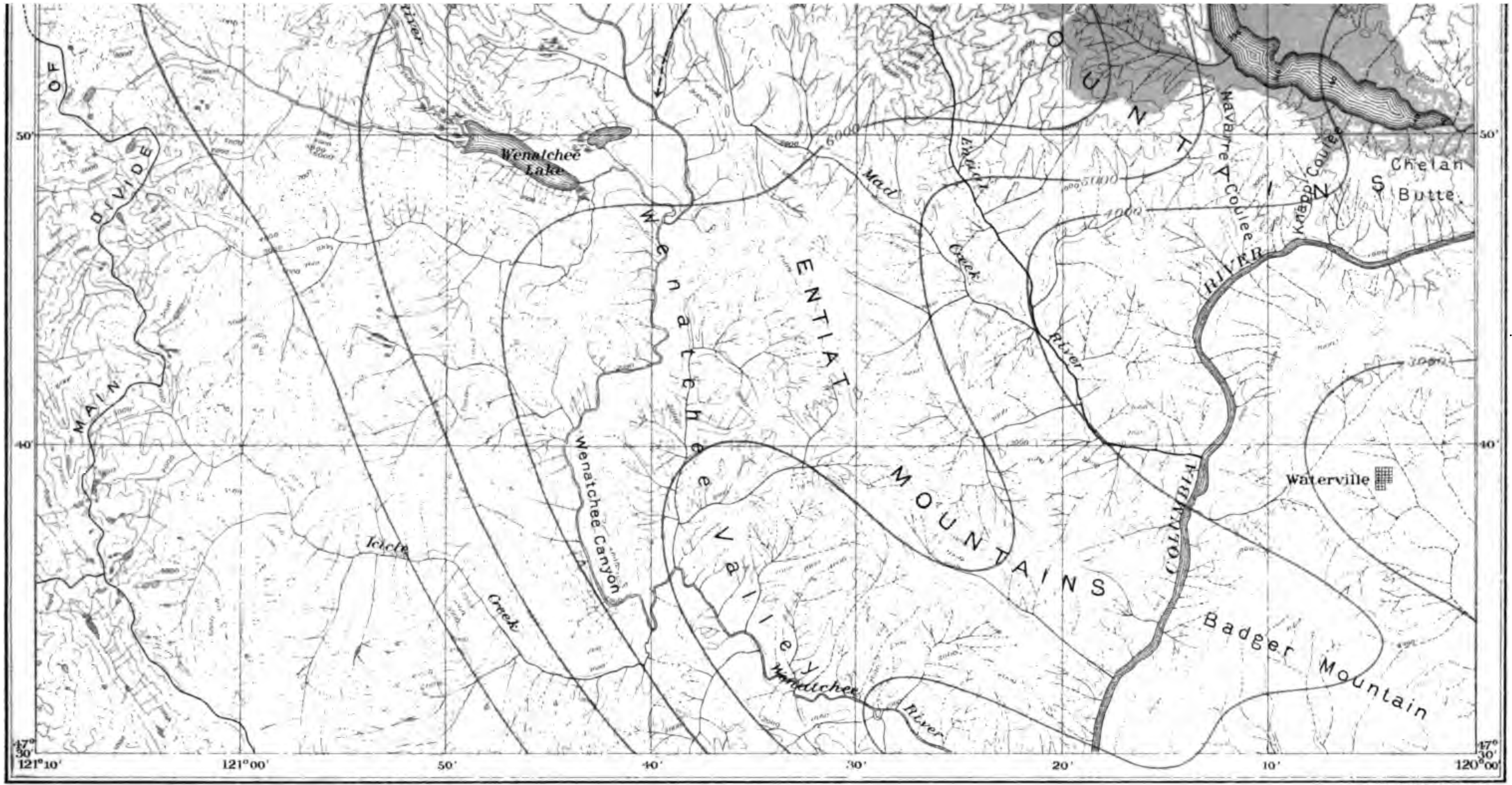
[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 144-145.


121°10'
121°00'
50'
40'
30'
20'
10'
120°00'
48° 30'
20'
10'
48° 00'
Cascade Pass
Bridge Creek
Stehekin Creek
Agnes Creek
Railroad Creek
Suiattle River
Glacier Peak
CASCADE RANGE
THE
White
Chiwawa
METHOW MOUNTAINS
CHELAN
Lake Chelan
The Narrows
Twisp
Methow River
River
6000
7000



MAP OF THE WENATCHEE-CHELAN DISTRICT
CASCADE RANGE, WASHINGTON

Physiography by
Bailey Willis, Geologist

Scale

5 0 5 10 15 miles

Contour interval 1000 feet

LEGEND

▨ Existing glaciers

■ Former extent of Chelan Glacier Similar glaciers occupied Methow and Wenatchee valleys, but their limits are not determined

☐ Contours on the warped surface of the Methow (Pliocene) peneplain as restored hypothetically where eroded

He asked for demonstration, which was difficult, since the suggestions of panoramic views failed to convince, but during his field work of 1900 he himself supplied the evidence of the existence of an old base-level plain on the hills of Yakima Valley, as stated in the first part of this paper. Of these results the writer was aware when he took the field in August, 1900, and he has found them of much value in tracing out physiographic relations in the vicinity of Lake Chelan. It would seem that the principal episodes in the history of the Cascade Mountains may now be stated with confidence.

In the field work of 1900 the writer was fortunate also in having the company of Prof. R. D. Salisbury, and statements concerning the glacial phenomena were suggested chiefly and often wholly by his observations and interpretations; but he is not responsible for the form in which they may here appear. The profiles which illustrate this article are drawn from topographic maps of the Chelan and Methow quadrangles, surveyed by Messrs. Griswold and Farmer, topographers of the United States Geological Survey. The writer has traversed much of the region with their maps in hand, and places confidence in the excellence and detailed precision of their work.

PHYSIOGRAPHY.

DESCRIPTIVE ANALYSES.

COLUMBIA GORGE, WENATCHEE TO CHELAN.

COLUMBIA CANYON.

The broad flood of Columbia River emerges upon the valley about Wenatchee from a noble gateway in the Entiat Mountains. The elevation of the river is somewhat less than 700 feet above sea. On the east the slopes of Badger Mountain rise to 4,200 feet, from which altitude the long, even profile of the summit declines gently eastward; on the west of the stream peaks of the Entiat Mountains in sight attain 5,700 feet, and these are the foothills of the Cascades. These heights of 3,500 to 5,000 feet that thus hem in the river spring from a flood plain one-half to three-quarters of a mile wide, and the profiles swing upward in convex curves, steepest near the foot. The effect combines grace and grandeur, the wide river, the broad gorge, and the great mountains harmonizing in their proportions.

Such is the view from a little distance. Upon entering the gorge the observer who follows the road along the western bank feels more closely shut in. On the one hand it is but a leap into the dark-green river swirling past fallen blocks of gneiss; on the other the cliff is near, and its crest, 1,000 to 1,800 feet above, is impressively high. The boldest profiles occur from 4 to 7 miles above Wenatchee, and one conspicuous point—Ribbon Bluff—with precipitous face projects into the gorge 12 miles farther upstream, 3 miles above the mouth of Entiat River.

Cliffs are not, however, the most characteristic features of the gorge. Along the eastern side they do not occur conspicuously, and even on the bolder western side they give place frequently to steep slopes in which rocky ledges project sharply through scanty grass and sagebrush. These steeps terminate above in points of long spurs, which rise westward with gradual slope to the highest summits of the adjacent mountains. The prominent angle between the steeper and gentler elements of the profile is an important physiographic feature, upon which broad deductions are based.

CHELAN BUTTE.

Looking upstream from near Ribbon Bluff, the view includes a summit higher than its fellows on the west bank and peculiar in the long sweep of its spurs in a concave curve from the top to within 800 feet of the Columbia, where the slope breaks off into the gorge. This is Chelan Butte (3,892 feet), the eastern end of a ridge which lies between the Columbia and Lake Chelan. Its graceful profile presents the first view had from within the gorge of those higher topographic elements which lie between the mountain tops and the steeps that shut in the river. The fact that this profile descends from Chelan Butte to within 800 feet of the river, whereas in the Entiat Mountains it ends 2,400 feet above the stream, is an index of the relative amount of recent uplift in the two places.

The graceful silhouette of Chelan Butte is broken near the extreme summit by sharp, rocky ledges, which support a narrow but flattish crest. They are formed by granite dikes cutting the softer gneiss. Peaks of this partially cliff-girt form occur isolated but dominant among the mountains west of but near the Columbia, and will hereinafter be referred to as monadnocks upon the Methow plain,[a] the remnants of which, so far as recognized in this region, will be described later.

THE EASTERN BANK.

The eastern side of the gorge differs markedly from the western. Not only is it in general not so bold of profile, but the forms of the slopes are genetically distinct. For a few miles above Wenatchee the bluffs on the east of the river almost equal those on the west in height and boldness where they rise to Badger Mountain; farther upstream, however, the slope recedes gently from the river, and, growing steeper, ends 2,000 to 2,300 feet above the stream in a mural escarpment 150 to 300 feet high. This wall crowning the height is the edge of a sheet of basaltic lava whose dark-brown color and columnar structure give it emphatic value in the otherwise gray and tawny landscape. In general the summit is even and nearly level, it being the western margin of the plateau of eastern Washington, and the line of the escarpment

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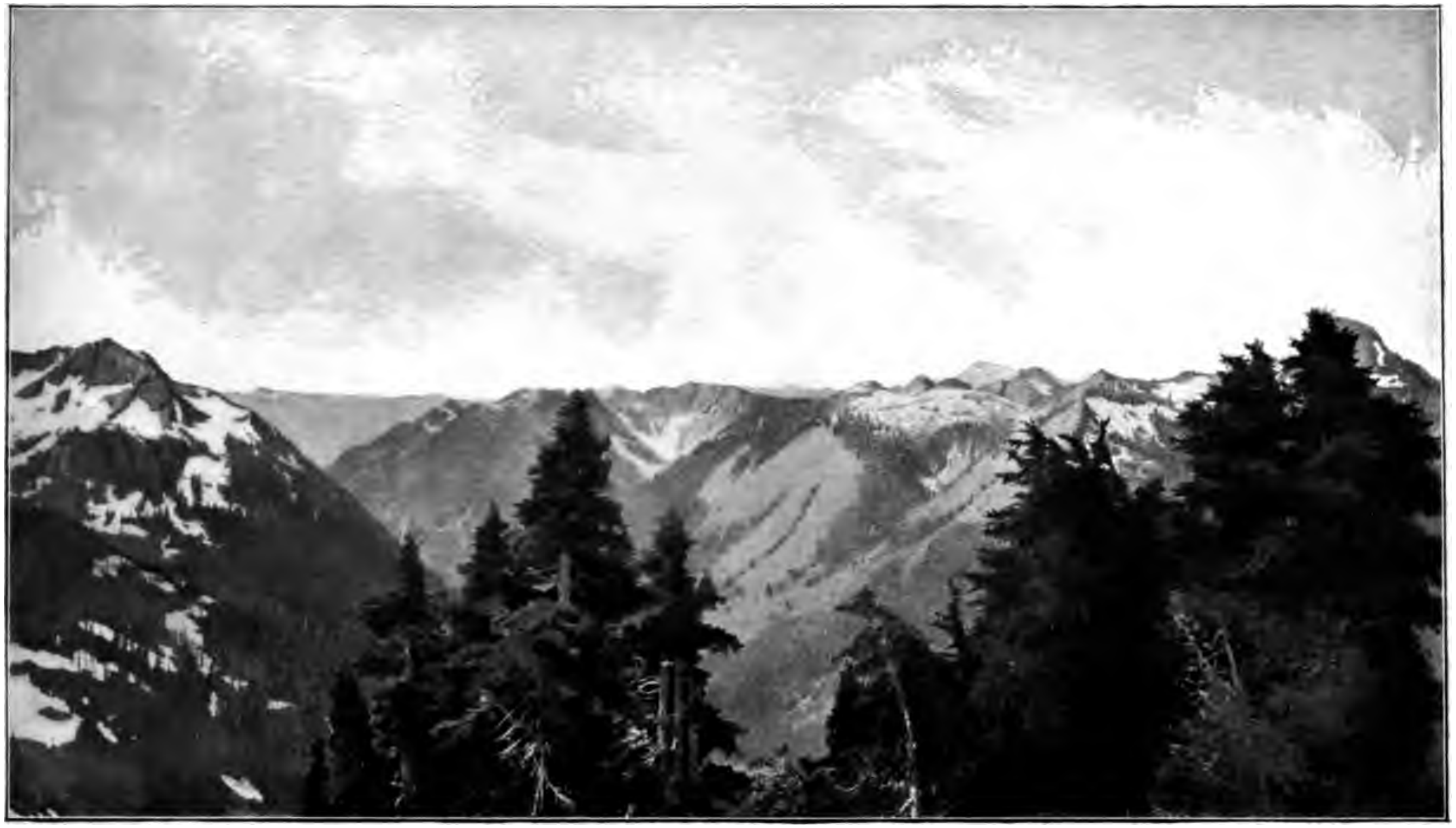

VIEW OF HIGH CASCADES FROM HEAD OF GOLD CREEK, SHOWING UNIFORMITY OF ALTITUDES.

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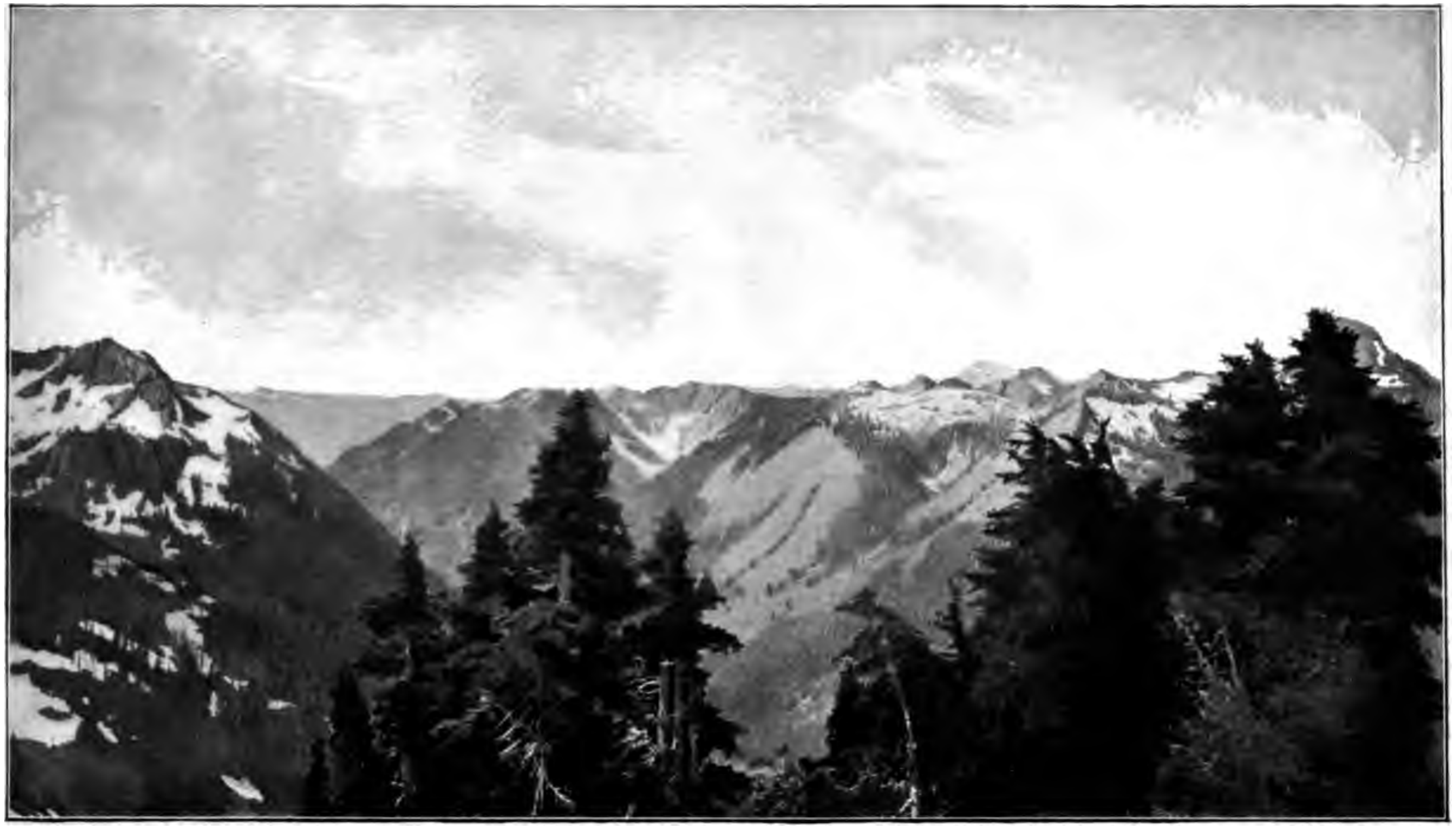

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is in sympathy with other level lines that cross the slope at various altitudes. Some of these lines are terraces due to landslides, others in ravines are terrace-like embankments that may be traced to the work of glaciers, and others much more continuous and nearer the river are stream terraces of the great Columbia itself. These last are represented on the western side of the gorge also.

Among the features which in any complete account of the region should be fully described are the several types of terraces of this eastern side of the gorge—the landslides, most common where the heavy columnar mass of basalt weighs upon the underlying schist and granite; the ice-built terraces, which are in part effects of tiny glaciers that gathered in the shaded lee of the plateau, in part results of occupation of Columbia Canyon by a tongue of a large glacier which, descending from the north, flowed down the river to a mile below Chelan Ferry; and the river terraces that extend for miles along the stream, their even tops sloping down its course and their perfect embankments rising near Chelan Ferry as much as 600 feet above the water. But all these features belong to a chapter of the history which is herein touched only incidentally—the very recent episode of glaciation.

BADGER MOUNTAIN AND WATERVILLE PLATEAU.

In its great sweep westward, southward, and southeastward across Washington Columbia River marks out the central plateau of the State. Most elevated near its western margin, this highland slopes in a general way east and southeast, and it is diversified both by channels and by uplands. The former, such as Grand and Moses coulees, appear to have been canyons of a large stream, probably the Columbia, but they are now nearly dry. The uplands are elevated portions of the plateau, connected with the lower parts by continuous slopes, usually not distinguished by scarp or steep.

Badger Mountain and the Waterville plateau are parts of this central district, situated at its extreme western margin and separated from the eastern foothills of the Cascade Range only by the canyon of the Columbia. It will appear later that there is in fact no separation in the sense that the mountain district west of the river has had an orogenic history different from that of the plateau east of it. But the rock structures and conditions of sculpture are so unlike that the two provinces appear at first sight to be physiographically and geologically distinct.

In the vicinity of Waterville the plateau presents an undulating surface, with a maximum but very local relief of 200 feet in a tenth of a mile. Well-defined but shallow drainage channels converge southeastward from a flat divide at 2,900 to 3,000 feet above sea. They constitute the headwaters of Moses Creek, which soon falls into a newly cut ravine. There was no water in any of the head streams in August, 1900, and the flow is not only intermittent but never large. The surface is deeply

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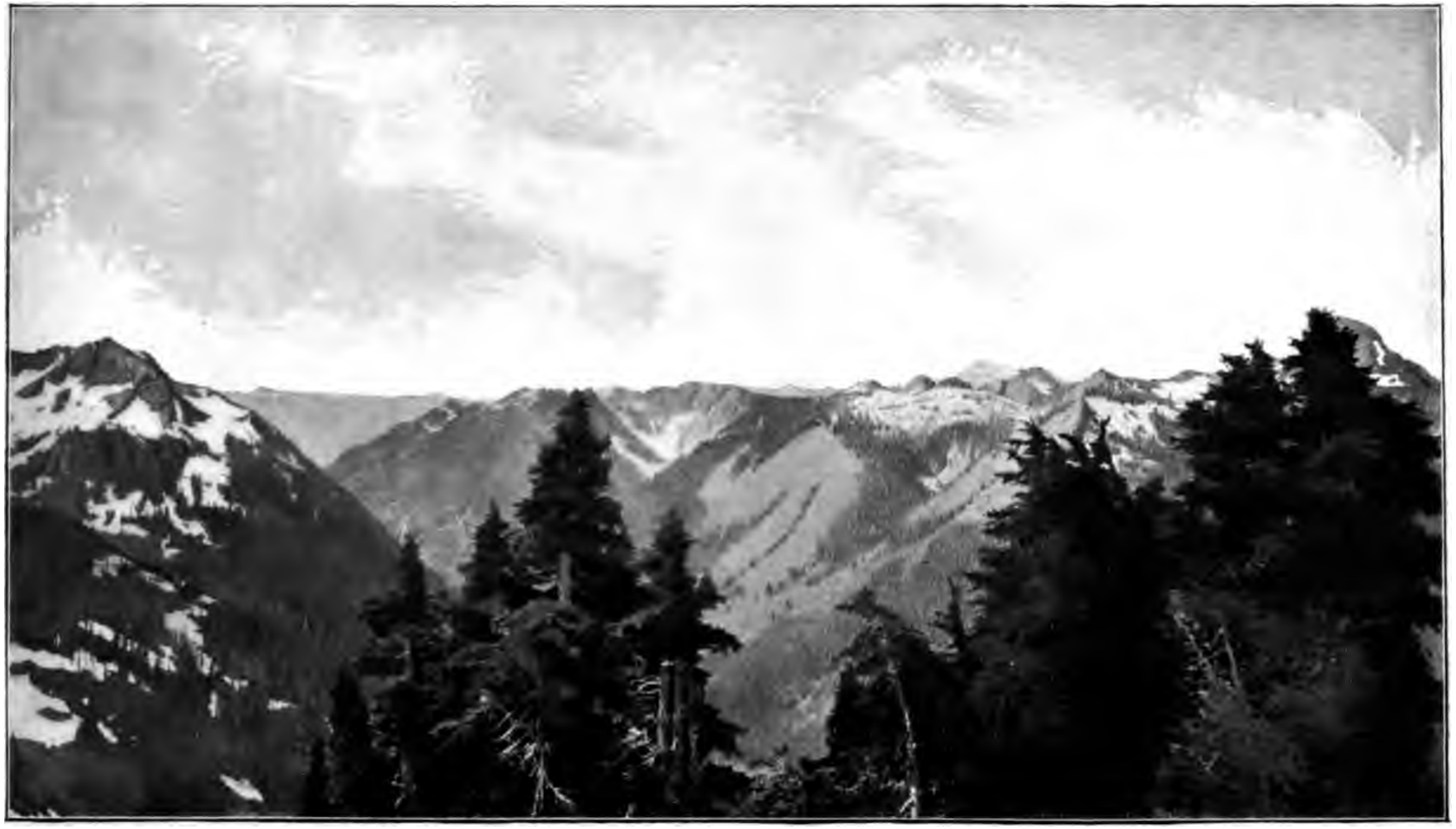

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In the flat spaces about the margin of the plateau, in the even divide between Coberly and Moses creeks, and in table hills southeast of Waterville, there are areas of considerable extent which are not now being eroded by streams. They present flattish surfaces, due to earlier low-level erosion, and are herein correlated as remnants of the plain once cut upon the basalt surface. From these remnants this plain is traced into the Cascade or Methow plain recognized by Russell.

Badger Mountain appears as a long, low hill when seen from the north from Waterville plateau. Although it rises 1,400 feet above the plateau, its slopes are so gentle, its surface so smooth, its length so extended, that it does not appear to be more than a hill. The summit is broad and flat, and long spurs with even slope extend not only northward but also southward several miles into the high valley of Rock Island Creek. Only when seen from the depths of the Columbia gorge or in relation thereto is Badger Mountain impressive, as toward the canyon it generally presents one or more mural escarpments of basalt crowning a confusion of landslide terraces, and it is conspicuous in height and mass.

The details of relief cut in its northern and southern slopes are more marked than those of the Waterville plateau, as might be expected from their steeper grade; but they are not accented by rocky walls, as are the similar features of Moses and Coberly creeks. Careful study of the two slopes of the mountain in riding across it discovered no conspicuous rock outcrops on the north or south. In the district of basalt flows, in which Badger Mountain lies, outcrops are rare where the dip of the basalt sheets and the surface slope nearly or quite agree; the outcrops are, on the contrary, conspicuous and continuous, like terrace walls, where a gentle dip of the sheets is beveled by a steeper surface slope. It is inferred, therefore, that the basalt sheets conform in a general way to the arched surface of the mountain, as they do to the surface of the Waterville plateau and of the synclinal valley of Rock Island Creek.

When the physiographic features of the mountain are compared with those of the plateau they are found to be very similar if not identical. In the plateau there may be recognized flats of an old lowland and later slightly developed relief. On Badger Mountain the flats may be identified in surfaces of long unmodified spurs and in the level summit, while the later relief appears more decidedly developed, but of the same stage as that of the plateau. The mountain therefore appears to be a part of the plateau, raised to a greater elevation without interruption of the slope. In consequence of altitude and accented grade, the mass is undergoing more rapid corrasion than the adjacent plains of like rock, but the process of dissection has made very little progress. Hence we may infer comparative inefficiency of the process or recency of relative uplift, or both.

TRIBUTARIES OF THE COLUMBIA.

The traveler following the eastern bank of the Columbia crosses but a single stream, Coberly Creek, whereas along the western bank from Wenatchee to Chelan he encounters in 35 miles six streams, of which three are rivers. This distinction is not limited to the short stretch under consideration, it being true of the Columbia throughout central Washington. From Spokane River to Snake River, 275 miles, no tributary of noticeable size enters from the east, while seven large rivers come in from the west. On the one side is an arid plateau; on the other, well-watered mountain systems.

Wenatchee River, Lake Chelan, the independent streams between them, and their tributaries drain approximately 30,000 square miles of high, mountainous country, which receives for the most part very heavy precipitation. The volume of water which they contribute to the Columbia is accordingly large. The three dominant rivers are Wenatchee, Entiat, and Chelan. Their courses are practically parallel, and at first sight, as stated by Russell,[a] appear to be simply consequent upon the surface slope of the uplifted Cascade Plain. Evidence will be given later to show that Chelan is a composite stream, made up of several parts united by piracy; and it is probable that Entiat also consists of parts of what were formerly distinct streams. The history of Wenatchee River is not made out in detail, but it has a wider branching system than the others, and may, like them, be a composite river. Reason will be shown later, however, for considering it an older river than Chelan, and one which has lost to the Chelan system an important part of its headwaters. The Yakima and Methow systems appear to be equivalent to the Wenatchee in age and general history, and these three may be classed with the Columbia as representing a drainage system from which the existing one is derived by adjustments.

The several valleys which join the Columbia from the west between Wenatchee and Chelan may now be appropriately considered.

WENATCHEE VALLEY.

Wenatchee Valley is developed on a mass of arkose sandstone lying between harder granite and gneiss. Whatever the antecedent conditions of drainage, adjustment to this soft mass and opening of a wide valley must result in time. The degree of adjustment attained and the extent of the valley appear to be such as to show that there has been adequate time. In one respect, however, the river exhibits an eccentric course. After flowing some miles southward in the sandstone area, it turns abruptly westward and crosses into the adjacent granite on the west. Russell[b] describes the depth of the canyon which the river has cut in granite as 3,000 feet, and the length 6 miles. An interesting problem is thus presented, and several alternative hypotheses occur in explanation. First, there is the idea that the meandering river was superimposed upon sandstone and granite at a time when their surfaces came to a common peneplain.[a] In this view the eccentricity is an original feature which adjustment has not yet modified. Second, the broad valley which exists in the sandstone may be looked upon as the original course of Wenatchee River, and the eccentricity of the present channel may be ascribed to diversion. A possible cause of diversion may be found in glaciation. As described by Russell, the Wenatchee glacier once filled the upper valley as far down as a point abreast of the present entrance of the river into the granite canyon. Under appropriate topographic conditions the ice might be competent to carry a stream flowing on its western margin over a divide into a small ravine adjacent, and thus the conditions for development of the present relations might be established. The fact that Upper Wenatchee River flows along the western side of its broad valley lends color to the hypothesis.

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[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 146.

[b] Ibid., pp. 140 and 158.

At present a low divide crosses the sandstone area south of the elbow which carries the Wenatchee into the granite. The divide is so low that it does not interrupt the view up the valley from Leavenworth, and its sky line falls in with the general elevation of neighboring hills of sandstone, while all such hilltops lie much below the granite and gneiss mountains on either hand. It is this view of a continuous valley which suggests the hypothesis of a formerly straight and now diverted course of Wenatchee River. The divide, nevertheless, requires explanation. Its elevation above that part of the valley upstream from it is a condition which could have resulted only from degradation of the upper valley, since the Wenatchee ceased to flow straight south across the divide. The depression of the upper valley may have occurred (a) through post-Glacial work of the diverted river; (b) during a glacial epoch through ice erosion by the Wenatchee glacier; (c) in interglacial time by degradation due to the diverted river, provided the stream was turned into the granite area during an earlier glacial epoch than that which is well known by its evident and widespread phenomena. Two epochs of glaciation are recorded in separate tills (the Admiralty and Vashon tills) in the Puget Sound Basin,[b] and the glaciers were there confluent from the Cascades, yet in the area of glacial erosion records of one epoch only have been found. It is possible that general uplift and erosion were incidents of an interglacial time and that the earlier glacial sculpture and deposits have been largely obliterated. Detailed study of the profiles and gravels of Wenatchee Valley and Canyon may throw light on the problem of two glacial epochs.

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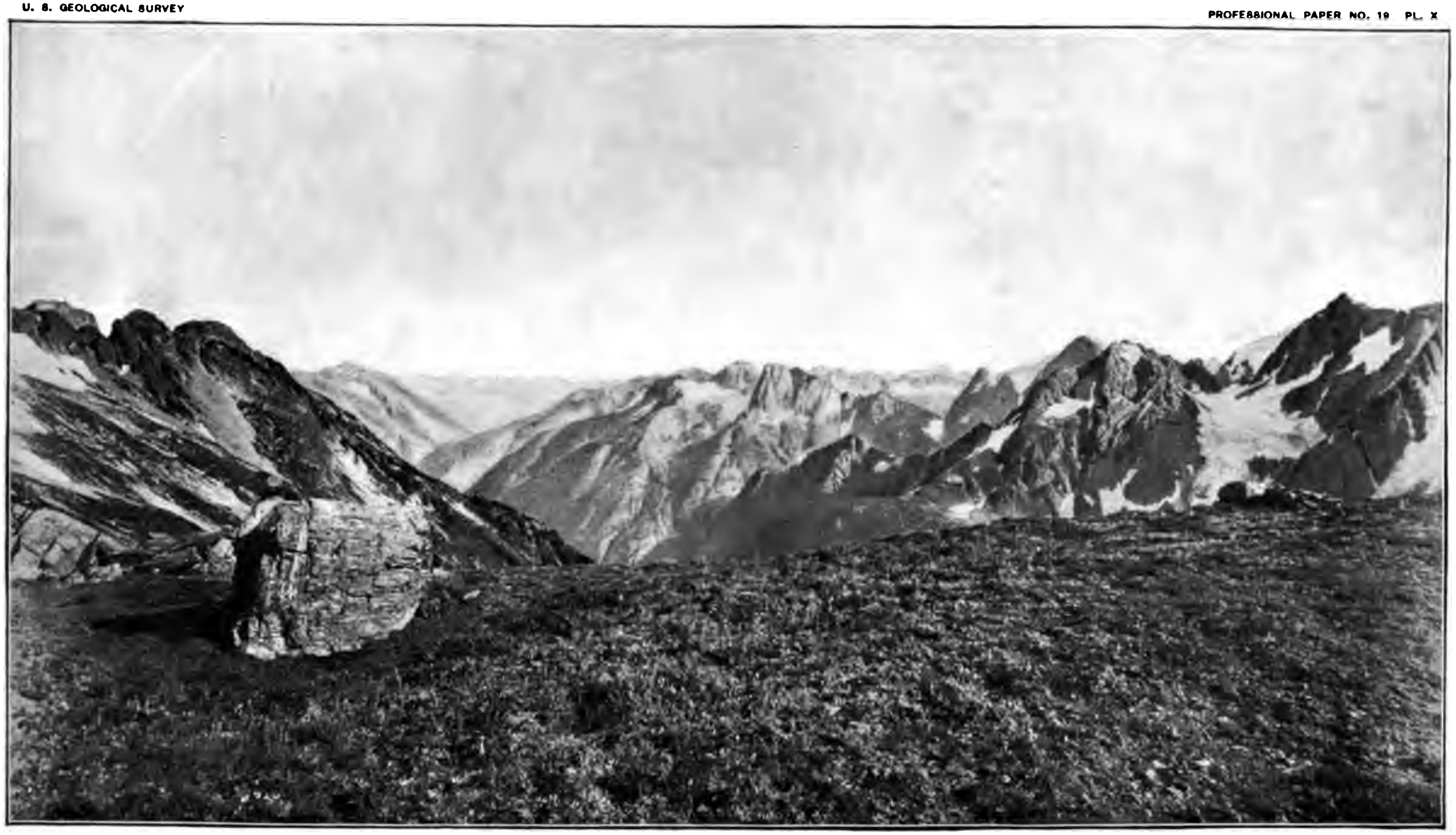
[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 140.

[b] Willis, Bailey, Drift phenomena of Puget Sound: Bull. Geol. Soc. America, vol. IX, pp. 111-162



VIEW OF HIGH CASCADES FROM NEAR CASCADE PASS, SHOWING UNIFORMITY OF ALTITUDES.

The effects of deformation which are described in the last sections of this paper may also be considered in this connection, and the area about Wenatchee Lake may be found to have been depressed or warped down relatively to the lower valley.

ENTIAT VALLEY.

Entiat River is a small stream among its fellows. It lies between Wenatchee and Chelan rivers, and its drainage basin is surrounded by the basins of these streams, which join around its head and cut it off from the high glacier-bearing district of the Cascades. The stream is about 35 miles long and has a straight course (S. 28° E.) to within 3½ miles of its mouth, where it turns east to the Columbia. The valley is very symmetrical and is limited by the parallel Entiat and Chelan mountains.

The Entiat flows in a deep gorge, comparable in form with, but narrower than, that of the Columbia. Near its mouth the steep slopes are about 1,500 feet high, and on the south, up to 2,600 feet above the river, the tributary ravines are sharply chiseled. North of the stream and 1,900 feet above it begin gentler slopes and broader features, which are connected with those that lie above the inner gorge of the Columbia. Up the Entiat, about the junction with Mûd Creek, the canyon appears to be but 1,200 feet deep and near Stormy Creek not more than 1,000 feet. These differences are coordinate with the grade of the Entiat, which from Stormy Creek to the Columbia falls 950 feet, and thus sinks that much deeper below the practically level contour of the base of the outer gentle topographic forms.

Three miles above Stormy Creek the Entiat Valley bottom is half a mile wide and the slopes of the canyon are continuously steep for 3,500 feet up to the closely adjacent summits of Tyee Mountain and the Chelan Mountains. This phase of the gorge is related in aspect and position to the section of Lake Chelan above Twenty-five Mile Creek. Each presents the appearance of a youthful canyon modified by glaciation, and their development will be further discusssd in stating the history of Lake Chelan.

The position of the Entiat Valley does not appear to be due to any zone of rocks weaker than others so far as the distribution of rock masses is known by examination of float in the river near its mouth and by traversing the Chelan Mountains. The area is one of gneisses and intrusives, probably related in intricate manner. The rocks of the crest of the Chelan Range are, indeed, dikes which are relatively hard, and the divide is determined by them; the Entiat Range may be similiarly crested; but these dikes of hard materials are not confined to the summits. They presumably occur irregularly within the Entiat Basin.

A simply fortuitous condition might determine the position of a minor valley like that of the Entiat between two larger ones, but there are some reasons for believing that chance has not been a dominant factor in this case. It will be shown that the Entiat Mountains are located on an uplift, which was there more pronounced than along adjacent lines. The trend of this uplift is northwest-southeast, and it now limits the Entiat drainage basin on the southwest. The Chelan Mountains are probably along a similar line of uplift. Thus the Entiat Basin apparently occupies the position of a depression between two uplifts, possibly a downwarp valley.

The stream is, however, older than the most recent earth movements which have affected its present course. The uplift of the region in general, and of the Badger-Entiat Range in particular, occurred in two distinct episodes, and the first limited the Entiat Valley. The river appears then to have flowed straight to the Columbia. Its old channel is marked by the gap in the spur southwest of its present mouth, the gap which is shown on the topographic map at the contour of 2,600 feet, and which is 1,100 feet below the hilltop that rises northeast of it. The interpretation is that the stream was checked by the later movement on the Badger-Entiat axis, and was diverted to a new course, its present easterly one. It has since then cut its inner canyon down 2,000 feet below the old one.

NAVARRE COULEE AND KNAPP COULEE.

Navarre and Knapp coulees are unlike ordinary valleys in several respects. First, they carry no running water, except that from a spring which in each flows out near the level of the Columbia, at the foot of a gravel terrace. Second, the rivulets that now flow from beneath the gravel filling and which gather from gulches tributary to the main coulee are disproportionately small when compared to the valleys they occupy. Third, the canyons which constitute their present upper sections continue beyond the divide and extend into the Chelan Basin. Fourth, they have wide, flat floors of gravel, the one 400, the other 600 feet above the Columbia. This gravel filling appears as a conspicuous terrace when viewed from the eastern bank of the Columbia. Fifth, the wash from the adjacent hills is so copious that alluvial cones are built clear across the flat-bottomed coulee, and thus sections of it are converted into hollows, which occasionly hold water and accumulate sediment.

In cross section the two coulees are miniatures of the Columbia gorge. Each exhibits a narrow valley or canyon within a wider valley and thus records episodes of development which are directly related to those of the great river. Like the Columbia, Navarre stream and Knapp stream had their beginnings back in the time of the ancient plain whose remnants barely survive in neighboring heights. Navarre was always much larger than Knapp, and its features are more conspicuously developed.

From the Columbia the ascent to Navarre Coulee is by a sharp V gulch, beyond which one rides out upon the surface of the gravelly flat 400 feet above the river

VIEW IN NAVARRE COULEE.

(see Pl. XI), and for 5 miles may follow the level bottom. One then enters a narrower canyon, marked on the west side by a conspicuous vertical wall of granite 800 feet high, and in three-fourths of a mile passes through this gate into a pretty glade lying level between wooded slopes. The head of this glade is an amphitheater, little more than 200 yards in diameter and steeply hemmed in. It is silent now save for the sighing of the pines, but at its farthest point is the vacant site of a cascade, whose voice once resounded from the surrounding hills. The fall was about 150 feet and the volume of water was large. The stream was a river flowing from the Chelan glacier, and by this pass the great mass of gravel which fills the lower canyon entered Navarre Coulee. At the end of the latest glacial episode the ice sank within the Chelan Basin and the river found a lower eastern course. The cascade, however, is only the latest incident in the history of the valley. Before the ice time Navarre stream had cut the inner canyon and before that the outer valley.

Above the cascade's vacant channel, as one rides out upon a gravel terrace from which the slope descends 600 feet to Lake Chelan, the emphasis of the environment is upon the recent glacial condition; but reverting to the earlier history one finds no apparent source of the older stream. The valley is cut clear through the divide and ends in the air high above any streams which might once have been its headwaters.

Knapp Coulee closely resembles Navarre, but on a smaller and less emphatic scale. Near its southern end and western side bare rocks rise boldly in the face of the gravel terrace below the channel of the latest glacial stream and formed the sill over which the cascade dashed. Northward and 500 to 600 feet above the Columbia the surface of the gravel terrace extends 2 miles to a narrower section, which corresponds to the conspicuous canyon of Navarre, and by this pass the open slope above Lake Chelan is reached. Again the valley is cut through the divide and at least 400 feet below it, but the headwaters of the stream which accomplished the task have been so diverted to lower channels that they can no longer flow through the pass; indeed, they can no longer be positively identified, except that they must now be tributary to Lake Chelan.

The history of these coulees is thus seen to comprise in order (1) an early stage of valley development at a surface now above the 2,000-foot contour; (2) a phase of canyon cutting, which was sharply accentuated in a space just south of the Chelan Basin; (3) the diversion of the headwaters; (4) the reoccupation of the channels by glacial streams, which, being heavily overloaded, filled them with gravel; (5) their present condition, in which they are being aggraded by wash from the steep side slopes, and reexcavation has begun in gullies facing the Columbia.

These incidents of individual history, especially the accented canyons and diversion of headwaters, fit in with other evidences in the interpretation of the character and distribution of deformation of the region.

LAKE CHELAN.

Lake Chelan is a slender body of water 65 miles long, whose southeastern end lies open to the sky between the grass-grown hills of the outer Columbia Valley, while its northwestern lies in shadow between precipitous mountains in the heart of the Cascade Range. There are sandy shallows near its outlet, but beneath the cliffs of its upper course the water is profoundly deep.

In brief technical phrase, the lake basin is a canyon modified, deepened, and dammed by glaciation. The canyon is that of the Stehekin-Chelan River, which rises in latitude 48° 30′ in glaciers of the Cascade Range at altitudes of 5,000 to 8,000 feet. The headwaters descend very abruptly, 1,000 to 1,800 feet in the first mile below the glaciers, and combine in a U-shaped valley of gentler grade, the fall being 2,500 feet in 23 miles. This section is cut in rock bottom. For 12 miles farther downstream the valley is floored with bowlders, coarse gravel, and sand, and the slope is but 20 feet to the mile, ending in the delta which the stream is building into Lake Chelan.

The gravel-filled section of the valley is no doubt deeply cut in the solid rock, since but a short distance beyond the front of the delta the lake is more than 500 feet deep. For a distance of 35 miles the depth varies from 1,000 to 1,400 feet, 1,419 being the maximum as yet sounded. As the water surface is but 1,079 feet above sea, the bottom of the lake is for a short stretch 300 feet below sea level, and an interesting question is raised as to how so deep a basin originated. Fifteen miles from its outlet the lake begins to shallow, and in its lower reach does not exceed 200 feet in depth.

The water is retained at its present level by a dam of sand and gravel, which in the section exposed by Chelan River is seen to consist of several successive members, i. e., soil, coarse stream gravel, till, very coarse gravel in pockets or channels, and cross stratified sands. The base of the drift is not exposed. This drift dam fills the preglacial valley by which the Stehekin-Chelan River once reached the Columbia, and the present outlet turns from the drift into the gneiss and granite south of it, and has there cut a deep rock gorge.

The topographic environment of Lake Chelan presents several distinct phases. (See Pls. I and XIII.) About the eastern end the general aspect is that of a wide, open valley bounded by hills 1,500 to 2,500 feet high. The slopes are marked by long, low spurs, whose profiles rise moderately, but with increasing angle upward to the summits. Slight hollows between them have consistent grades. The surface is that of mature topography characterized by profiles which are concave upward, but on traversing the hilltops one notes in their flattish and rounded forms that the stage of maturity is not everywhere completely developed, else the ridge crests would be sharp, and sympathetic with the active corrasion of the slopes. The earlier phase is not, however, distinctly traceable in these summits.

Upon this mature surface are cut and built certain younger features. Where the major spurs sweep downward to the level that once was the valley floor and become gentle in slope, they end abruptly in steep or precipitous facets which break directly down to the lake shore and are about 400 feet high. These bluffs might readily be attributed to ice erosion, in view of the conspicuous evidences of glaciation in the Chelan Basin, but they are traced and correlated with the steeps which wall the inner gorge of the Columbia below the limit of any glacier, and they therefore are similar elements of the Stehekin-Chelan canyon which was cut within the mature topography of an earlier date.

Terraces which fill the hollows and occasionally skirt the slopes for some distance occur at various levels up to 1,100 feet above the lake. Their topographic position, relations among themselves, and constitution show that they formed in lakelets confined on the hillside by spurs and on the now open side by the glacier which occupied the Chelan Basin. A full discussion of them belongs to the glacial history of the region.

In the view from Chelan Butte northwestward, the lower section of Lake Chelan is seen for a distance of about 15 miles to occupy the wide basin just described. Its trend in this stretch is north by west 8 miles, and thence due north 7 miles. Along the western side of the latter reach runs a bold ridge, whose even crest is 3,600 to 4,200 feet above the lake and whose eastern face descends precipitously nearly to the water. A marked feature of its scarp is a deeply stained surface, freshly exposed, which is locally known as Red Slide. The lake trends westward around the northern end of Red Slide ridge and disappears from view among lofty mountains. The Methow Range lies north, the Chelan Range south, both rising to more than 7,000 feet above sea within 5 or 6 miles of the lake, and both sending out long, high spurs which maintain altitudes of 6,000 feet above sea to within 2 miles or less of the lake. From these spurs descend very steep slopes, scored by little ravines and worn by glacial action.

Sunk deep among the mountain heights, the fiord-like lake extends 32 miles. The grandeur of the scenery readily lends itself to superlative description, but exact statement must be moderate. The walls of the canyon are sloping, not precipitous. Bare and gray and desolate, the mountain sides and cloud-draped peaks are very impressive, but though their height be 6,000 feet above the lake they nowhere tower in precipices like Yosemite walls. The maximum inclination is usually near the water surface, and for a hundred feet or so may locally approach 60 degrees. Generally it is less than 40 degrees. And from this steepest facet the profiles rise in a curve which is convex upward, and pass into the nearly level spurs of the adjacent ranges. The narrowest and boldest section of the canyon is just above Safety

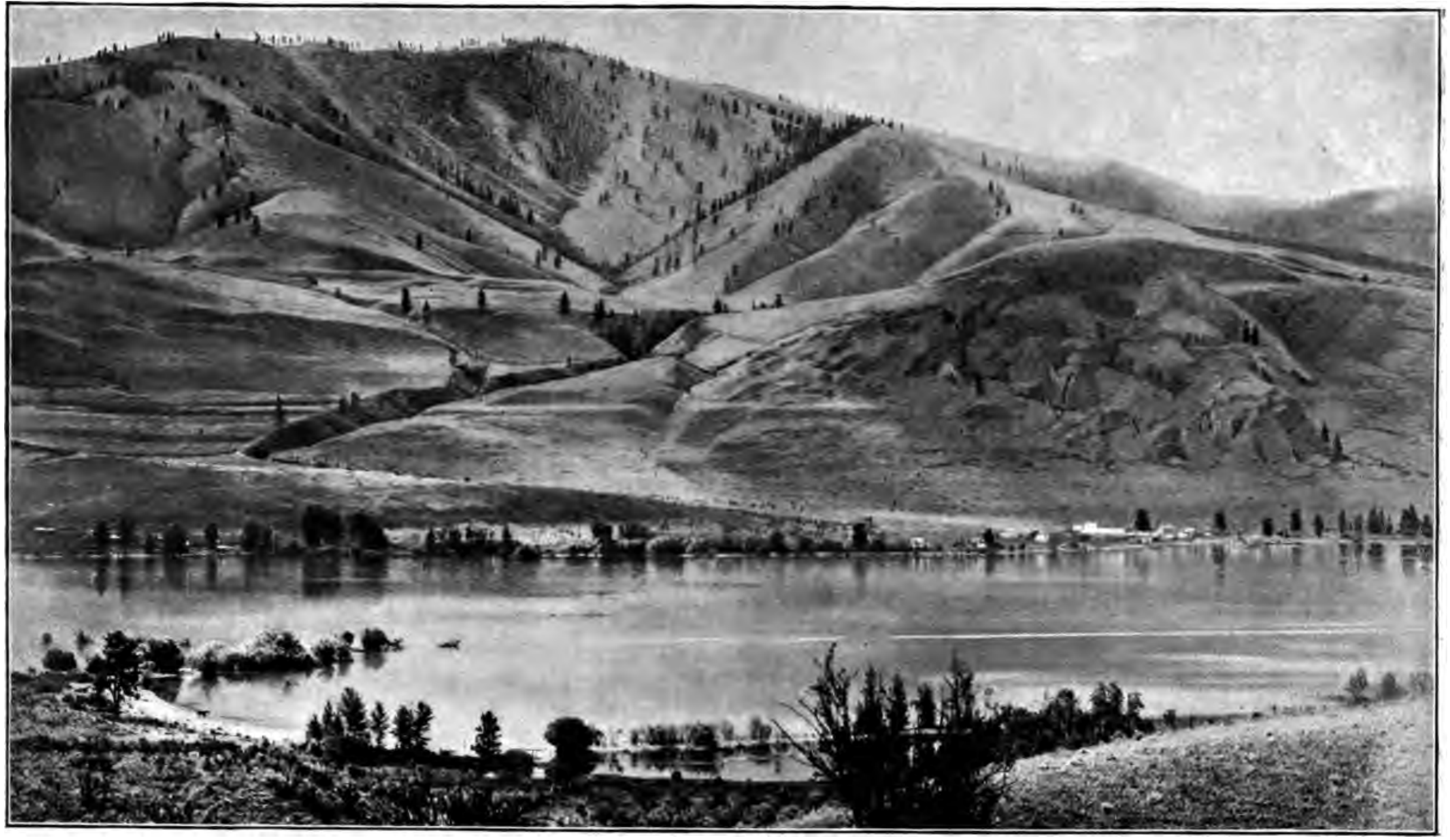
Harbor Creek. It is called the Narrows and is shown in the view Pl. XIII, and in profile in fig. 5 of Pl. XIX.

The physiographic features of the fiord lake are readily correlated with those of the Columbia River gorge. The steeps of the latter are not only homologous with the walls of the former, but they are mutually traceable one into the other through Navarre Coulee, Knapp Coulee, and the Lower Chelan Basin. That they are due to a common activity—the familiar corrading action of a stream—is apparent. They differ, however, in certain aspects. The gorge of the Columbia exhibits acute pinnacled rock ledges cropping through slopes of soil and loose rock. The canyon of Lake Chelan presents massive rounded bosses of rock, cleaned and worn down by a mighty scouring action. This is the work of ice which, as a glacier, flowed through the fiord, driven by the accumulations in the tributary valleys of the Cascade Range.

The diverse aspects of the Chelan Basin invite discussion. Its lower valley section and its upper fiord-like extent are of different topographic stages, the one being mature, the other young. Their diversity may be explained as the result of either one of two conditions or of their combination. The lake basin below Twentyfive Mile Creek may be cut in softer rocks than the part above that stream, and its more advanced topographic development may be due only to a consequently greater rate of erosion. Or the section below Twentyfive Mile may actually date farther back in time than the upper portion, and may have attained its present stage through longer exposure only. But in the view now held by the writer both of these conditions have been effective.

As to the rocks in large masses they may be considered in two classes. The softer ones are gneiss and schist; the harder are jointed intrusive rocks. Granite occurring as dikes outcrops in bold ledges in Chelan Butte and elsewhere, and is one occasion of the high divide south of eastern Chelan Basin. Rhyolite-porphyry and granite-porphyry dikes stand out ruggedly as the crest of the Chelan Range, and similar rocks occur extensively in the Methow Range, at least about the head of Safety Harbor Creek. On the other hand, the rocks seen north of the eastern part of Lake Chelan are micaceous and schistose. In so far as these differences coincide with heights and hollows, we may attribute a certain effect to them, and the most conspicuous instance of such coincidence is found about Lake Chelan below Twentyfive Mile. But on the whole the region is characterized by indifference of topographic phase to rock structure, and the distinctions described are not adequate in themselves to explain the great features of Lake Chelan.

A number of facts go to show that the Stehekin-Chelan canyon is a composite one, and that the development began at the east and extended westward. In that case the eastern section dates farther back, and its advanced topographic aspects



CHELAN BUTTE FROM NORTH SHORE OF LAKE CHELAN.

gentler than it was toward the basin of lower Lake Chelan at the place where Chelan drainage headed against it. There can be no question but that the development of that slope caused vigorous growth of the head branches of streams rising on it, and that capture and diversion of any river less favorably situated must result. That there was such a river appears to follow from the recognition of an old valley which now lies at a great elevation and is completely dissected. In describing this feature it will be convenient to name it, and it will be called Russell River.[a]

The valley of Russell River was first recognized in the summer of 1899 in a view east and northeast across the Entiat and Chelan mountains. On the southeast the Mount Stuart group formed the right wing, and on the northwest the high summits of the Cascades were the left wing. In the far distance on the horizon lay the basalt plateau of central Washington. According to expectation, the Chelan and Entiat mountains, extending from the high Cascades on the west to the basalt plateau, should descend in a general slope without marked depression along the mid-sections, or decided elevation in the eastern ends. But such depression and elevations were striking features of the view. Stormy (7,219 feet), Baldy (6,432 feet), Tyee (6,688 feet), and heights in the eastern Entiat mountains not yet mapped stand higher than those portions of the ranges between them and the Cascades. The profiles of the lower mid-sections of the ranges are peculiarly flat and suggested cross sections of a shallow valley. The heights east of the mid-sections are traversed by the deep canyons of Entiat River and Chelan, such canyons as should be formed by streams attacking an elevated bench and retrogressively cutting into it. The slope of the supposed bench forms the eastern side of the Cascade mass and is a necessary feature connecting the mountain block with the lower surfaces on the east. And a stream flowing on the bench and parallel to its face in the general position of a valley corresponding with the lower mid-sections of the range would be peculiarly liable to capture.

When in 1899 this hypothesis of the former existence and complete diversion of Russell River was framed, equal consideration was given to another explanation. It was that the depression along the mid-sections of the ranges was due to a zone of weak rocks, which had wasted faster and yielded lower divides between the attacking streams. In 1900 these hypotheses were tested so far as practicable. The depression was clearly recognized from various points of view on the Chelan and Methow mountains, and it was visited at the only place accessible to the route followed. This place is in the southwest corner of the Methow quadrangle (see Pl. XVII), about the head of Lake Creek. The divide between Lake Creek and Lake Chelan is 5,900 to 6,000 feet above sea, and the heights on the east rise above 6,700 with points over 7,000, while those on the west reach 8,500 feet at a considerable distance. The low

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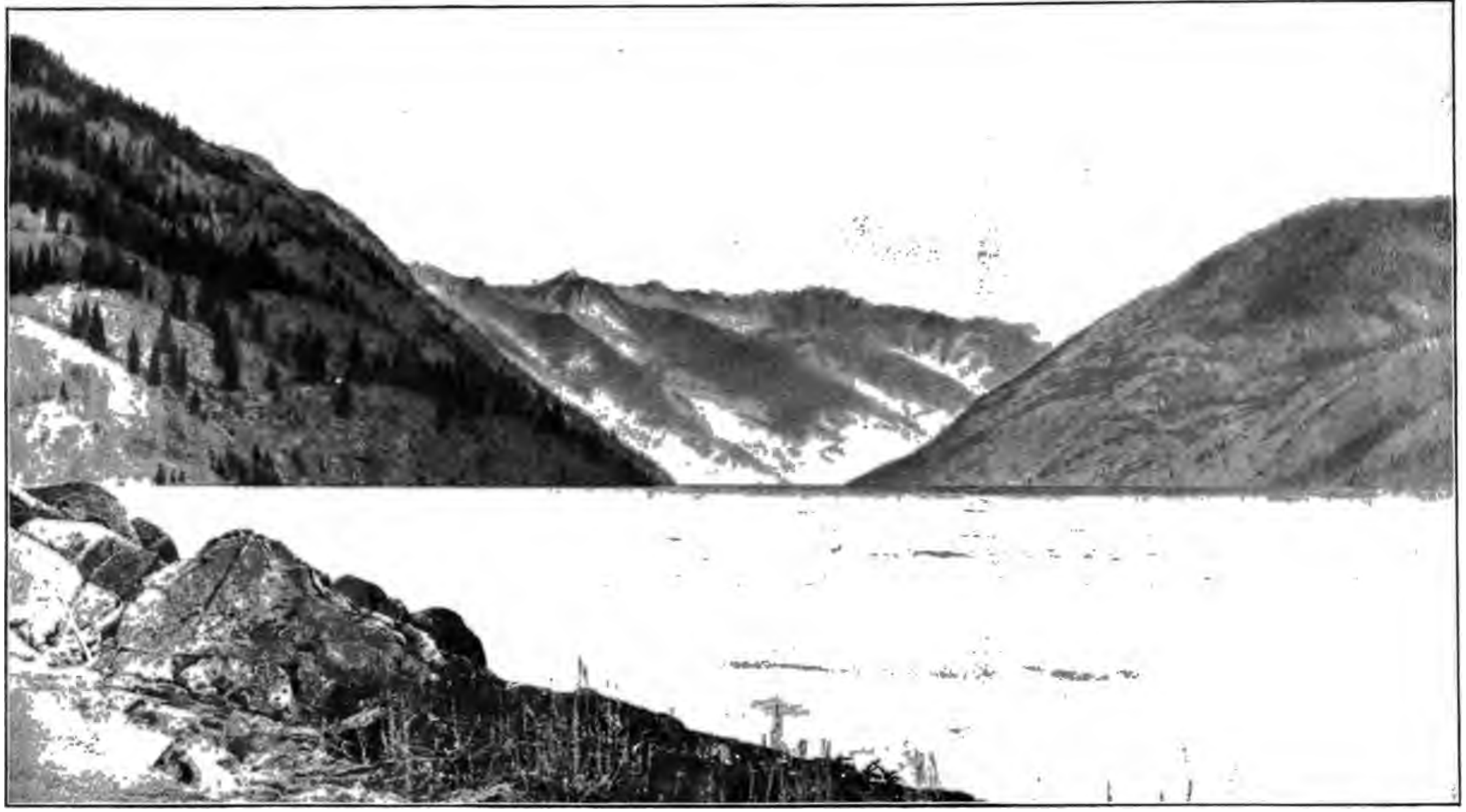
[a] In honor of Prof. I. C. Russell, who first published an account of the Methow plain, on which the river flowed



NARROWS OF LAKE CHELAN.

ENTIAT MOUNTAINS.

To see the Entiat Mountains against the sky and in their relation to the Columbia gorge and Badger Mountain, one should ascend the spur between Navarre and Knapp coulees to an altitude of 3,100 feet. Thence Badger Mountain presents an unbroken even-topped height which is taken up by the Entiat Mountains and carried westward for 2 miles till it rises into conical peaks 800 feet higher. (See profile 7, Pl. XIX.) The otherwise uniform sweep is broken by the great valley of the Columbia, which clearly exhibits its inner gorge and outer slopes. Restoring what the river has cut away, the topographic continuity of Badger and Entiat is apparent, and they are also geologically a unit, since the basalt and gneisses occur in similar relations in both.

The continuity of structure and profile of the mountains which the Columbia divides shows that they are of one mass that moved as a unit in the uplift of the region. Similar reasoning and conclusion apply to Waterville plateau and the mesa north of Entiat River. They also, though divided, are of one mass, but their surfaces lie 1,000 to 2,000 feet lower than the mountains. The river's trench is deeply cut in both masses, but if we filled it to the brink between the plateau and the mesa, the stream could not flow across the higher mountains before it. It is clear that when the river adopted its course the mountains were not higher than the plateau, but that since that time the Badger-Entiat mass has been raised higher than the region north of it. As has already been pointed out, this uplift sufficed to cause the diversion of the lower part of Entiat River, but it did not rise with sufficient rapidity to turn the great master stream, the Columbia.

The broad flat at the eastern end of the Entiat Range, 4,500 to 4,900 feet above sea, corresponds in extent with a basalt remnant. The dip of the basalt is not less than 3 degrees and probably nearer 5 degrees to the north. The slope of the surface is about 1½ degrees in the same direction. The dip and slope therefore appear to diverge 150 feet or more to the mile. If we assume that at any time the surface was level, the basalt then dipped 1½ or more degrees, and the level crossed the basalt beds at a slight angle. It is more probable that the surface declined slightly down the course of the Columbia and was cut across the nearly level basalt. Both have been tilted in the uplift of the Entiat Range.

Though small, the angle at which the flat surface and the basalt bedding diverge is important, since the surface is thereby identified as one of erosion in contradistinction to one of structure. The evidence is slight and by itself insufficient to establish a conclusion, but it is sustained by the fact that in this region similar flats are cut across structurally indifferent gneiss and granite, and it is corroborated in the Yakima district by the definite observations of G. O. Smith, with which it is in line.

CHELAN MOUNTAINS.

From Columbia River at Navarre Coulee an Indian trail leads to Stormy Mountain, the highest point of the Chelan Range, and following the crest for some miles in a northwesterly direction crosses the Entiat Valley and the Wenatchee Mountains toward Leavenworth. Like most Indian routes in this region, it was chosen from among the many possible ones because it presented little difficulty to the passage of horses, the ridges followed being of gentle rise. To this fact of topographic form and to exceptions to it, attention is now called.

After a sharp scramble of 1,200 to 1,600 feet it is a surprise to ride out upon nearly level or broadly rounded surfaces which are deeply mantled with soil. Yellow pines (*Pinus ponderosa*) grow vigorously, but widely spaced, as is their habit; the surface is scantily covered with grass, and groups of shrubs stand here and there. A few hundred feet to right and left this surface rounds off into steep slopes that descend to adjacent hollows. Follow a lateral spur of the ridge and you come to a cliff, the margin of a larger ravine. Pursue your course northward along the ridge and you ascend easily, though with occasional slight descent, to about 4,000 feet above sea. Gradually the ascent becomes steeper to the top of a ridge at 5,000 feet, and following this two miles to the eastern side of Baldy Mountain you strike a moderate slope of limited extent at about 5,500 feet above sea. Above this Baldy presents a serrate ridge whose highest tooth attains 6,432 feet above sea. The height, the ragged angular forms, and bare talus all mark the hardness of the rocks, rhyolitic porphyry and granite, which occur in a system of large dikes traversing hornblende-gneiss. Stormy Mountain (7,219 feet), the spur (7,142 feet) 8 miles northwest of Baldy, and much of the intervening crest are sustained by similar dikes and present the same acute topographic forms, but adjacent to them, at elevations above 6,000 feet, there are gently rounded flattish surfaces, which are physiographically not in sympathy with the active work of frost on the peaks above or the energetic corrasion progressing in the ravines near by. These flats are of small extent, but of definite character. The most apparent one lies between Twentyfive Mile and Lake creeks, where the divide trends north, leaving the dike system of rhyolitic porphyry that runs out in the sharp peak at 7,142 feet. For convenience, it may be called Fourmile Ridge. The prevailing rocks of Fourmile Ridge are granite and gneiss, which afford no structural occasion for the flattish surface. For a distance of 4 miles the summit has a general elevation above 6,600 and below 6,800 feet, declining gently northward. It is slightly notched at several points, and even where it widens out it is rounded, not level. But lying as it does between steep and even precipitous slopes which descend a thousand feet into the adjacent depths, its grassy, soil-covered surface is a striking remnant of an earlier physiographic condition. It is a derivative from a plain, and although modified it has not lost its significant aspect, a long and practically continuous uniform slope. (See profile 5, Pl. XIX.)

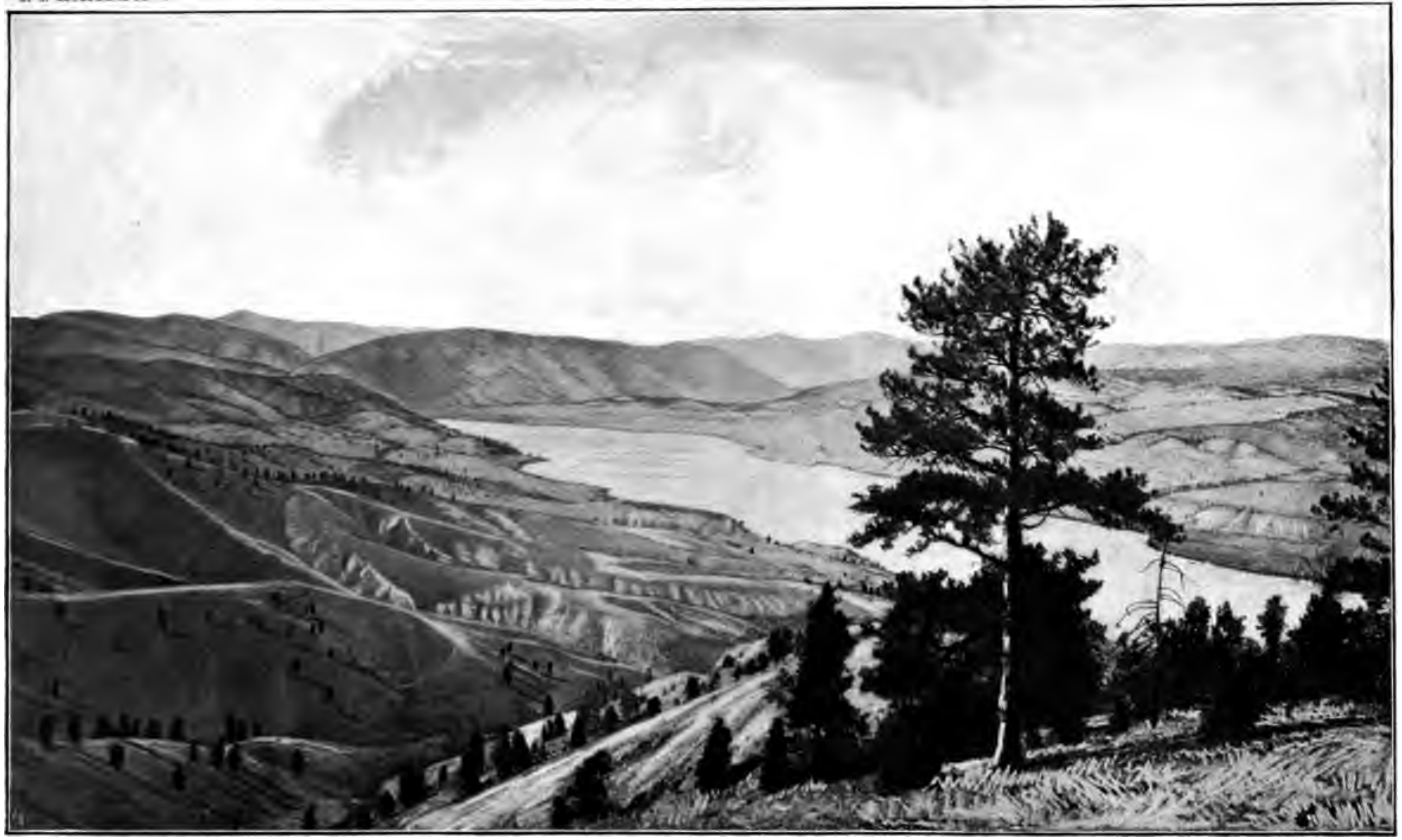
Had the rider, ascending from the Columbia along the old Indian trail, turned southwest on the level above the 3,000-foot contour, he might have followed the divide between the Columbia and the Entiat, over the broad hill having an altitude of 3,757 feet, and out onto the bit of plateau or mesa which overlooks the junction of the two rivers. As may be seen from the topographic map, the accents of the ridge are slight, but the ravines carved in its sides are acute. The surface at an altitude of about 3,757 feet, its northeastern and southwestern spurs, and the mesa southeast of Strummel Canyon are peculiarly broad and simple forms as compared with their environment. The mesa exhibits occasional basalt scarps and is a corner of the Waterville plateau isolated by the Columbia Gorge. Through its structural and physiographic characters it is an important link between the great plateau and the Chelan Mountains. Approaching the mesa in form, but unlike it in rock structure, the hill having an altitude of 3,757 feet continues the same topographic phase, and its spurs extend the type on the one side to the Entiat Gorge, on the other to Navarre Coulee.

Considered as a whole, these features are clearly distinguishable from the steeps which are now subject to energetic corrasion by brooks and rivulets. Considered in detail, two less clearly distinct phases may be recognized among these broader features. Discriminating by form we may find surfaces which approach a plain and those which are marked by moderate relief; judging by relative elevation, we shall discover the plainer surfaces above the more clearly sculptured ones, but without definite boundaries between them. Carrying the comparisons over wider areas the flats are found at different heights, but always in the same physiographic relations.

Thus, physiographically, the mesa, the spurs of the hill with an altitude of 3,757 feet, and Fourmile Ridge belong to one and the same stage. The crests of the hill which has an altitude of 3,757 feet, of Baldy, of Stormy, and of the hill which has an altitude of 7,142 feet, are older monadnocks, whereas the long spurs of the range fall into the class of later features, and the canyons of all magnitudes into that of the latest.

METHOW MOUNTAINS.

The Methow Mountains lie between Lake Chelan on the southwest and Twisp and Methow rivers on the northeast. Only their southeastern portion, up to Star Peak, is included in the accompanying map (Pl. XVIII) and in the profile (Pl. XIX). A portion of it, known as Sawtooth Ridge, extends with serrate and glacier-bearing peaks into the heart of the high Cascades.



VIEW FROM CHELAN BUTTE, LOOKING NORTHWEST OVER LOWER LAKE CHELAN TO STORMY MOUNTAIN AND NAVARRE PEAKS.

At their eastern end the Methow Mountains are no higher than the neighboring plateau east of the Columbia. Like the Entiat and Chelan mountains they are structurally continuous with the plateau, from which they are separated only by the canyon which the river has cut. Looking northward from Chelan Butte or the margin of the plateau above Chelan Ferry, the sky line of the plateau is continuous with that of the Methow Mountains at an altitude of about 3,400 feet. Rising westward with moderate grade the peaks of Navarre are reached, 7,800 to 8,200 feet above sea, and thence northwestward for many miles the summits are of remarkably uniform altitude.

As a mountain mass between Lake Chelan and the parallel valleys northwest of it, the Methow Mountains are 12 to 15 miles across from southwest to northeast. They have a very definite watershed from which all streams flow by the shortest routes to Chelan, Twisp, or Methow rivers. West of a line drawn north and south about 3 miles east of Navarre Peaks the crest is narrow and often ragged, but high spurs extend out on either side to distances of 3 or 4 miles, maintaining in their heights the general altitude of the watershed. Navarre Peaks are the southeastern representatives of a large number of points which closely approach or slightly exceed 8,000 feet in elevation, and which are linked together by high ridges branching from and on a general level with the central divide. These peaks and spurs are clearly derivatives from a plateau.

The eastern part of the summit exhibits some broad areas, and from them the spurs decline gradually, especially toward the southwest. As compared with the deep canyons cut in them, these surfaces belong to an earlier stage of topographic development. They are residuals which distinguish the district east of an ideal line from the region of acutely mature topography west of it. The distribution of these residuals and of the drainage lines flowing southwest and northeast suggests that the surface between the Methow and the Chelan east of Navarre Peaks would, if restored, form an arch pitching southeast and merging in that direction into the basalt plateau. Traced westward this arch flattens out in a level above the summits of the higher part of the range.

In topographic forms and drainage the Methow Mountains present most interesting problems which involve the discussion of earlier topographic phases, deformation, stream adjustment, and glaciation. But the writer's opportunities for observation have not been sufficient to solve them.

SYNTHETIC DISCUSSION.

GENERAL STATEMENT.

In the preceding pages the separate features of the region have been described as they now are, and their interpretation in terms of topographic development has been suggested. In what follows it is proposed to discuss each stage of that development from the earliest recognized up to the latest glacial epoch. The glacial phenomena are very conspicuous and have been noted from the terraces of the Columbia to the lingering glaciers of the Cascades, but their record is one which is more complex than can be read without special studies which are yet to be made by an experienced glacialist. That chapter is therefore not included in this discussion.

Enough has been said in the descriptions to indicate that several stages of topographic development have been recognized. They are clearly evident in such a profile as No. 1, Pl. XIX, from the Entiat Mountains across Columbia Canyon to Badger Mountain. Beginning with the highest, the peaks (5,700 to 5,800 feet) and the flat adjacent to them are considered to be representatives of the oldest stage of which definite evidence remains. They are correlated with Badger Mountain, the Waterville plateau, surfaces in the Chelan and possibly the Methow Mountains, and the level from which the high Cascades are sculptured. This oldest stage is therefore that of the Cascade plateau, as named by Russell, but now called the Methow stage. It is also identified by G. O. Smith. The characteristic topographic type of the Methow stage was a plain, upon which residual hills survived. Following Davis, it may be designated a peneplain, with monadnocks.

Within this plain were carved valleys which appear to have attained nearly mature development. That of the Columbia in profile No. 1, Pl. XIX, appears to have been 2,000 or 2,500 feet deep and 7 or 8 miles wide. The smaller streams certainly developed shallower and narrower valleys, but remnants of the Methow plain west of the Columbia were few and limited. On account of its preservation in the basin of the Entiat, this stage is named from that river. The characteristic topographic form of the Entiat stage is mature. It occurs as a spur or divide below occasional residuals of the Methow stage and above features of later stages.

Within the relief of the Entiat stage there were cut deeper channels, some of them canyons of impressive depth, many of them simply mountain ravines. They constitute the most marked and everywhere the most characteristic features of the topography of the region. Any large stream might be chosen as exhibiting the type, but probably none shows it in various degrees better than the Twisp, which from its junction with the Methow to its source in the Cascades lies in a canyon that varies from a few hundred to 4,000 feet in depth, as can be seen on the Methow topographic

The following tabulation expresses the most reasonable estimates of correlation for the several stages in geologic time.

Physiographic development of the Cascade Range.

Physiographic stage.	Type locality.	Nature of characteristic activity.	Date, if one uninterrupted Glacial epoch.	Date, if two or more Glacial epochs.	Period.
Stehekin	Stehekin sources and valley.	Glacial retreat and reexcavation of old valleys.	Post-Glacial to present.	Post-Glacial to present.	Recent.
Chelan	Gorge of Lake Chelan and terraces of the Columbia.	Glacial occupation of canyons, canyon modification, and valley filling by overloaded streams. Glacial diversion of streams.	Glacial epoch ..	Latest Glacial epoch.	Pleistocene.
Twisp	Canyon of the Twisp, Methow quadrangle.	General acceleration of corrasion, resulting in excavation of canyons and ravines with readjustments of drainage.	Pre-Glacial.....	Inter-Glacial ...	Pliocene or Pleistocene. (Sierran Age.)
Entiat	Basin of the Entiat and foot spurs of the Chelan Range.	Development of mature topography generally throughout the Cascade plateau.	Pre-Glacial.....	Earlier Glacial epoch.	
Methow	Generally throughout the broad mountain district, and specifically in Yakima Valley.	Planation by erosion to a low plain with monadnocks.	Pre-Glacial.....	Pre-Glacial.....	Pliocene.

METHOW STAGE.

CONDITIONS OF DEVELOPMENT.

The characteristic feature of the Methow stage was a plain, and where now recognized the essential form of the remnants is a flat, or approaches a flat, from which the existing surface is immediately derived. The plain might have originated through (*a*) marine deposition, (*b*) marine planation, (*c*) as the original surface of a lava flow, (*d*) by erosion to a peneplain.

(*a* and *b*) Marine deposition and planation are excluded from among the possible conditions of development of the Methow plain, because the surface extended over hundreds of square miles without being in any way conformably related to any sedimentary formation, and is cut unconformably across the bedding of the youngest sediments of the district, the Ellensburg formation.

(*c*) The original surfaces of Miocene basalt flows probably coincide with the Methow plain in some areas of the Columbia Basin, and it has been thought that these coincidences were so extensive that the plain was determined by the basalt, at least as far as the flows extended. The writer's local observations about Waterville and west of the Columbia are not satisfactorily definite in this regard. At the one point where dip of the basalt could be seen in the Entiat Mountains there is a slight unconformity, but generally no good observation was possible. In the Yakima district, however, where the evidence of coincidence was thought to be most striking, G. O. Smith has observed a general unconformity, which, though commonly slight, is often considerable, and, though the angle of divergence be small, it is sufficient to carry the plain diagonally across the great thickness of the basalts, from older to later rocks. Thus in a broad view the unconformity is unmistakable, and the plain is not identical with the surface of the lava flows.

(*d*) The extent of the Methow plain as observed by Russell and the writer is more than 10,000 square miles. It has been identified by Russell, Smith, and the writer as a feature cut upon nearly all rocks of the region, the schistose metamorphics, the Tertiary arkose sandstones, the bedded basalt flows, and the pumaceous clastics of the Ellensburg formation. These facts are consistent with but one interpretation, that of widespread planation by agencies of subaerial erosion to a plain approaching base-level. The Methow plain, therefore, represents a flat lowland. The plain has been observed not to agree with nor pass over some summits of granite, granite-porphyry, rhyolitic porphyry, and other intrusives. These eminences are regarded by the writer as monadnocks, which mark a certain degree of incompleteness in planation.

Criteria of recognition.—The characteristics by which areas of the Methow plain are identified are flatness, unsympathetic relation to environment, and relative elevation. Flatness is not used in a mathematical sense. No topographic feature is a plane, and it is not probable that any area of the old plain survives with unmodified surface. An approach to flatness is all that can be looked for. Flat does not mean level. The old plain had indeed a very low slope, but in course of elevation to the altitudes at which it is now found—3,000 to 9,000 feet—it has acquired relatively steep inclinations at some places.

An unsympathetic relation of a topographic feature to its environment is that relation in which the feature could not develop or in which the prevailing activities are working to destroy it. An elevated flat crowning steep slopes is in an unsympathetic relation to its environment. Less obviously, but not less truly unsympathetic, are long, smooth slopes and spurs subject to attack by streams retrogressively developing their channels. In the usual case the unsympathetic feature is a residual, which still retains in part a surface developed under a different environment, but where the original surface is all eroded the unsympathetic form may still be seen in inherited features or relations. Thus uniform elevation of mountain summits is interpreted as inheritance from a plain which was dissected in consequence of elevation. The uniformity is not in sympathy with the height. There are, furthermore, degrees of unsympathetic relations. The extreme is that existing between a plateau and a canyon, between passive age and aggressive youth. Of a less degree is the diversity between a wide or rounded ridge crest and slopes which approach maturity. And canyons cut in maturely developed topography afford examples of least conspicuous unsympathetic relations

Relative elevation is an important factor in recognizing remnants of the Methow plain, but in this respect elevation above sea is less significant than position above other features. Since in course of physiographic development an older residual feature commonly lies above all younger forms, we should look for remnants of the plain, the oldest surviving phase, at the greatest altitudes in any locality; but where the plain falls below any summit we are constrained to recognize the latter as a residual, or monadnock, upon the plain.

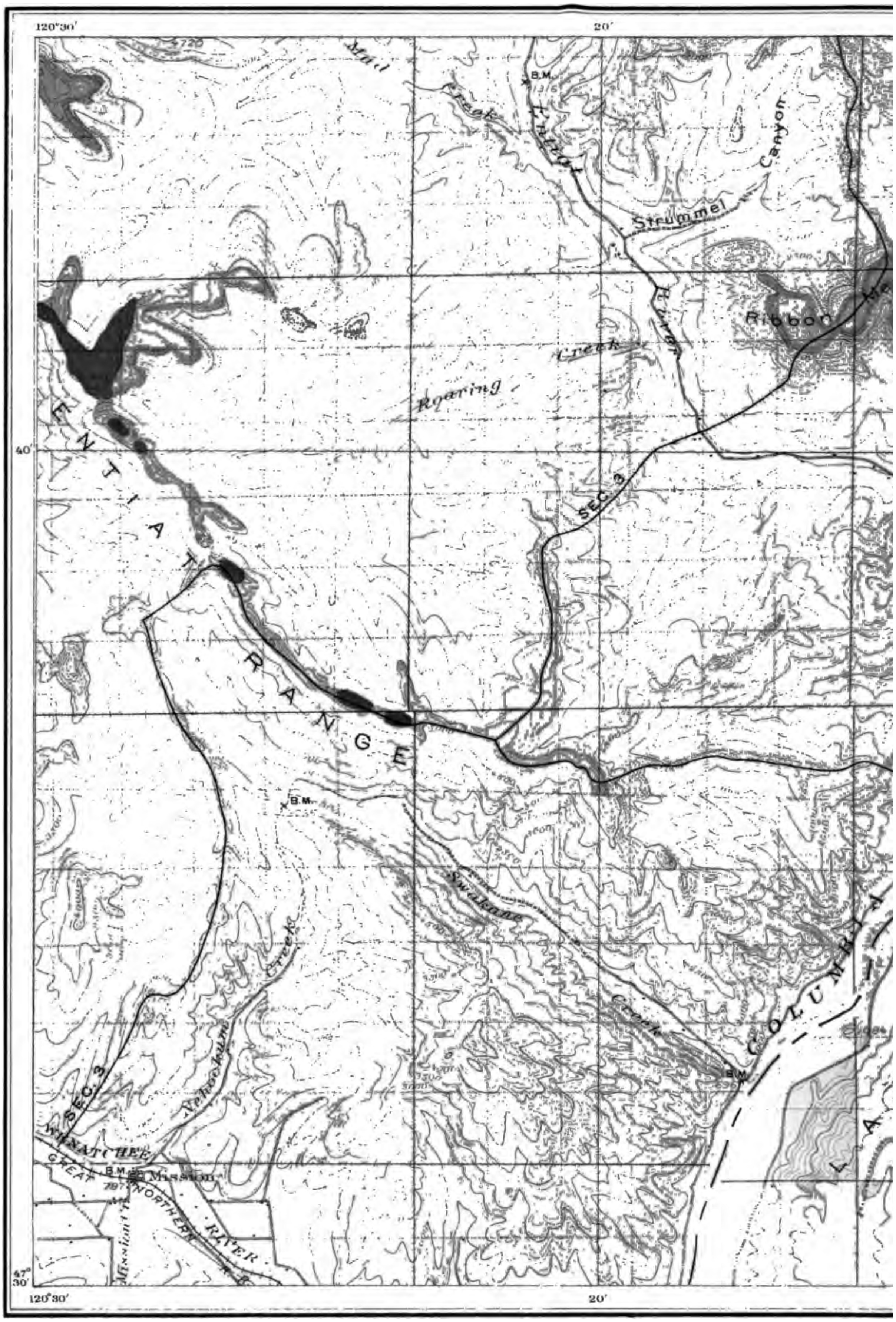
Distribution and character of residuals.—Detailed geologic surveying with adequate base maps has been carried out in the Cascade province chiefly by G. O. Smith. His identification of the Methow plain in the Yakima province is described by him in the earlier part of this paper, to which the reader is referred. In what follows the plain is traced in the district between Wenatchee and Methow and in portions of the high Cascades seen by the writer.

The distribution of recognized residuals is shown on the maps, Pls. XVI, XVII, and XVIII. The mapping is an adaptation of observation to base map, carried out in the office and largely guided by the topographer's delineation of forms. Exact boundaries can not be recognized in the field, except occasionally for short spaces, and none are attempted in the graphic statement. The areas delineated as representing the Methow plain are not thought ever to correspond exactly in surface with it. They have been modified slightly by corrasion and materially by disintegration and wind erosion; but they retain the typical character of the plain sufficiently to demonstrate its former existence and to represent it.

In the Waterville plateau wide areas are characterized by flatness. They occupy the positions of broad divides and are commonly distinguished from lower, gently sloping surfaces by an intermediate steeper facet. They are unsympathetic to the slightly accented drainage channels, and they fall into one general plain. They probably correspond nearly with the surface of basalt flows, but no outcrops of the rock were observed, deep soil prevailing everywhere within sight of the writer's route except on the scarps toward Columbia River. Their great extent removes them from the category of surfaces possibly due to rock structure only, and their other characters identify them as residuals of an ancient lowland plain of erosion.

Two isolated hills southeast of Waterville and the nearby spurs of Badger Mountain are believed closely to approach the flat of the Methow plain. The spur east of the main road from Waterville across the mountain most nearly continues to the summit an unbroken surface, which may be considered representative. The top of Badger Mountain has the character of the Waterville plateau, and long, even spurs extend this aspect into the valley of Rock Island Creek on the south. Independent physiographic evidence of Columbia Canyon and some meager structural facts show that the mountain is an anticline of later development than the

U. S. GEOLOGICAL SURVEY



R U Goode, Geographer in charge
Triangulation by W. T Griswold
Topography by R.A.Farmer and W.T Griswold
Surveyed in 1897-98

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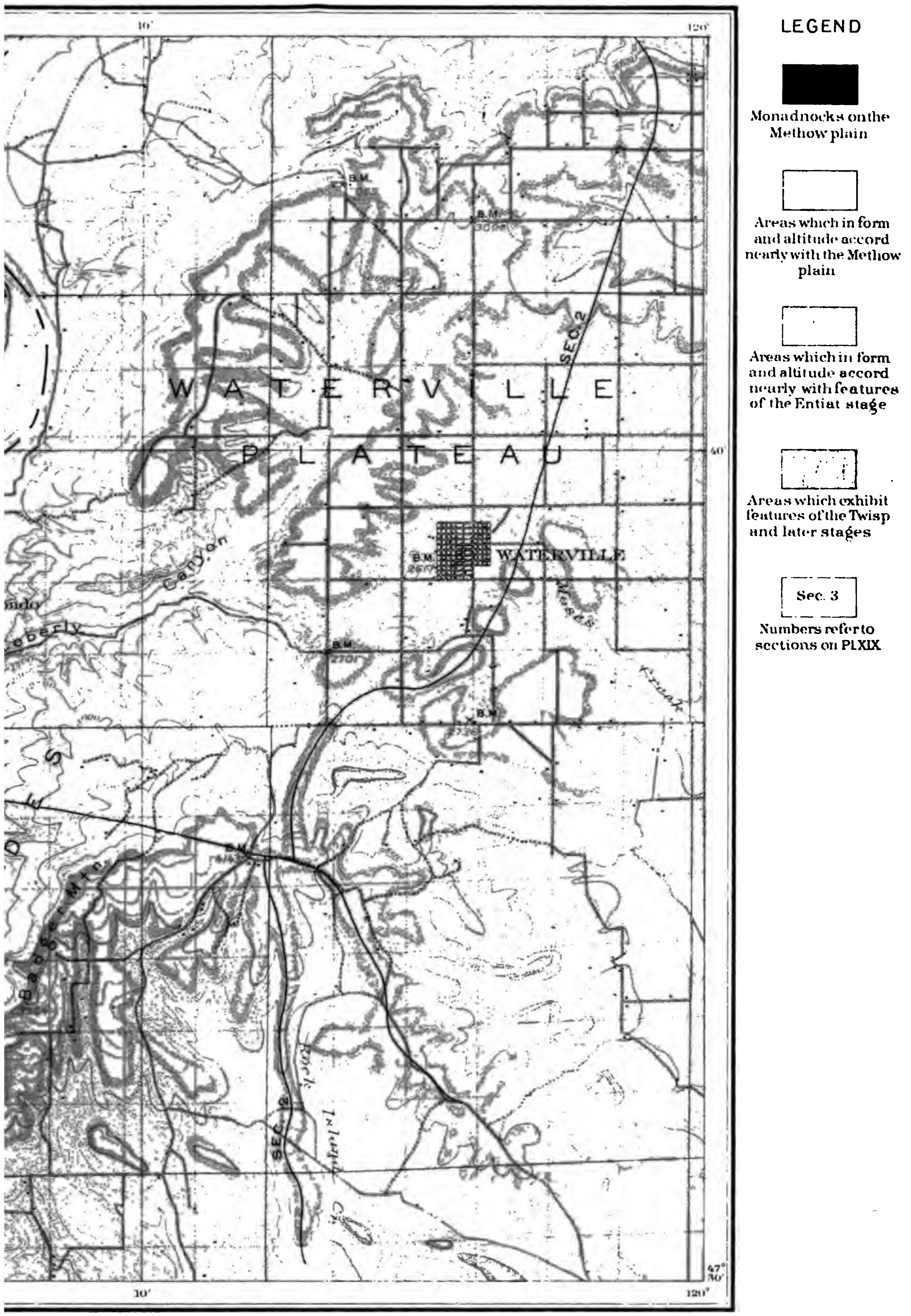
LEGEND
Monadnocks on the Methow plain
Areas which in form and altitude accord nearly with the Methow plain
Areas which in form and altitude accord nearly with features of the Entiat stage
Areas which exhibit features of the Twisp and later stages
Sec. 3
Numbers refer to sections on Pl. XIX
10'
120°
40'
47° 30'
WATERVILLE PLATEAU
WATERVILLE
SEC. 2
SEC. 2
B.M.
B.M. 3006
B.M. 2617
B.M. 2701
B.M.
B.M.
Canyon
Moses
Creek
Badger Mtn.
Pork
Cr.

THE CHELAN QUADRANGLE
E COLUMBIA CANYON, AND
ADE RANGE

4 miles

Physiography by
Bailey Willis, Geologist

Methow plain, which should accordingly rise above the arch or to a greater or less degree coincide with it. In general profile the coincidence appears to be close; the summit and southern slopes are probably not much modified; but the northern slope is dissected until very little, if any, part of the surface represents the plain.

South of Rock Island Creek the characteristic broad expanses extend to the escarpment above the Columbia gorge and their sky lines are continuous across the canyon with the heights of Table Mountain, from which they descend to the Yakima Valley.

The Methow plain west of the Columbia is preserved in a few small remnants only. The even slope on basalt in the eastern end of the Entiat Mountains, 4,800 to 4,900 feet above sea; Ribbon Mesa, 3,300 feet; spurs above the contour of 3,400 feet on the hill, which reaches an elevation of 3,747 feet; and Fourmile Ridge, 6,700 feet, have all been described. They are topographic flats which are on the whole not determined by structure planes of the basalt, where there is basalt, and which occur on jointed and schistose rocks as well, which are not in sympathy with their present environment, and which have, to later topographic stages, the relation that the Cascade plain holds. Therefore, in spite of their considerable and diverse altitudes, they are identified as residuals of that once continuous lowland.

It is possible that detailed study of the Chelan Mountains between Baldy Mountain, Ribbon Mesa, and Chelan Butte will discover other bits of the plain on summits of spurs and about monadnocks. There is room for question whether the hill which rises to an elevation of 3,757 feet is a monadnock or not. The plain may sweep above it, but the general interpretation of facts would not be modified in any essential particular by such changes in the determination of local positions.

Of the Methow Mountains the writer has not seen the portion east of Navarre Peaks except in general views from a distance. Their profile thus seen is characteristically that of a tilted, somewhat dissected plain. They rise with continuous line from the plateau level east of the Columbia from 3,400 feet or less to 6,000 feet above sea. They then appear to sweep up in a steeper but moderate grade to the heights of Navarre Peaks at 7,800 feet. The topographic map and the profile derived from it (fig. 4, Pl. XIX) confirm this observation. Along the crest, from 3,400 to 6,000 feet above sea, there are residual surfaces of flat form unsympathetic to their environment. One extends from 3,600 feet to 3,800 feet. There is then a rise over Cooper Mountain, which is probably a monadnock, about 300 feet above the plain. Beyond this the flats occur near or above 5,600 feet, with ascent to 6,100 feet, and thence upward the crest is sharp. Navarre Peaks might be regarded as summits older or younger than the flat surfaces—as monadnocks or descendants;[a] but, considered in their relations to the many heights of about the same altitude which occur west of them and connect them with the general level of the high Cascades, Navarre Peaks appear to be descendants, and the plain sweeps up to and over them.

The reconstruction of the Methow plain has proceeded thus far upon identification of residuals, which actually or so nearly represent its surface that they may be taken for it. In extending the reconstruction further over the Methow Mountains and the high Cascades, another line of reasoning must be followed.

In the Cascade Range views from high altitudes present two striking features, that mutually are in strong contrast. The one is the acuteness of the mountain forms, often sharply needle-like; the other is the uniformity of general elevation which these boldly sculptured peaks approach. The sharp forms result from the activity of frost and thaw, of corrasion, and of transportation in shattering and removing rock masses, whose principal controlling structure is steep jointing. The uniformity of heights has been interpreted as inheritance from a former plain surface, and also an effect of erosion at great altitude.

The latter hypothesis has been considered in view of facts closely resembling those observed by Dr. Dawson, its author, in the same mountain range, but it does not seem to be sustained. The activities of erosion do not appear to tend toward more uniform effects with greater altitude, on the contrary elevation emphasizes their locally unequal intensities. Corrasion and transportation are effected by falling water, whose energy for a given mass is directly as the fall, and consequently increases with height of land. Corrasion and transportation are very narrowly localized in activity, and hold the same relation to general degradation that a circular saw does to a planer. Their intense application results in deep canyons, the extreme of height and depth. Disintegrating influences, whether chemical or mechanical, may act equally with equal opportunity, but they are controlled by conditions of exposure. Upon an uneven surface these are varied and they become more and more diverse as inequalities of relief develop. The suggestion that frost and thaw may with elevation gain in effectiveness more rapidly than corrasion and so may limit the height to which peaks may attain in a growing range, appears not to be sustained by study of mountains much higher than the Cascades, nor by theoretical reasoning in regard to the work of freezing water. Thus after careful consideration the writer has felt obliged to abandon the hypothesis of development of a common high level among mountain peaks.

The general level of Cascade summits is suggested in the views, Pls. IX and X. The one is the central section of a panorama of three views, looking southwest

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[a] A descendant is a topographic feature carved from the mass beneath an older topographic form which has been removed.

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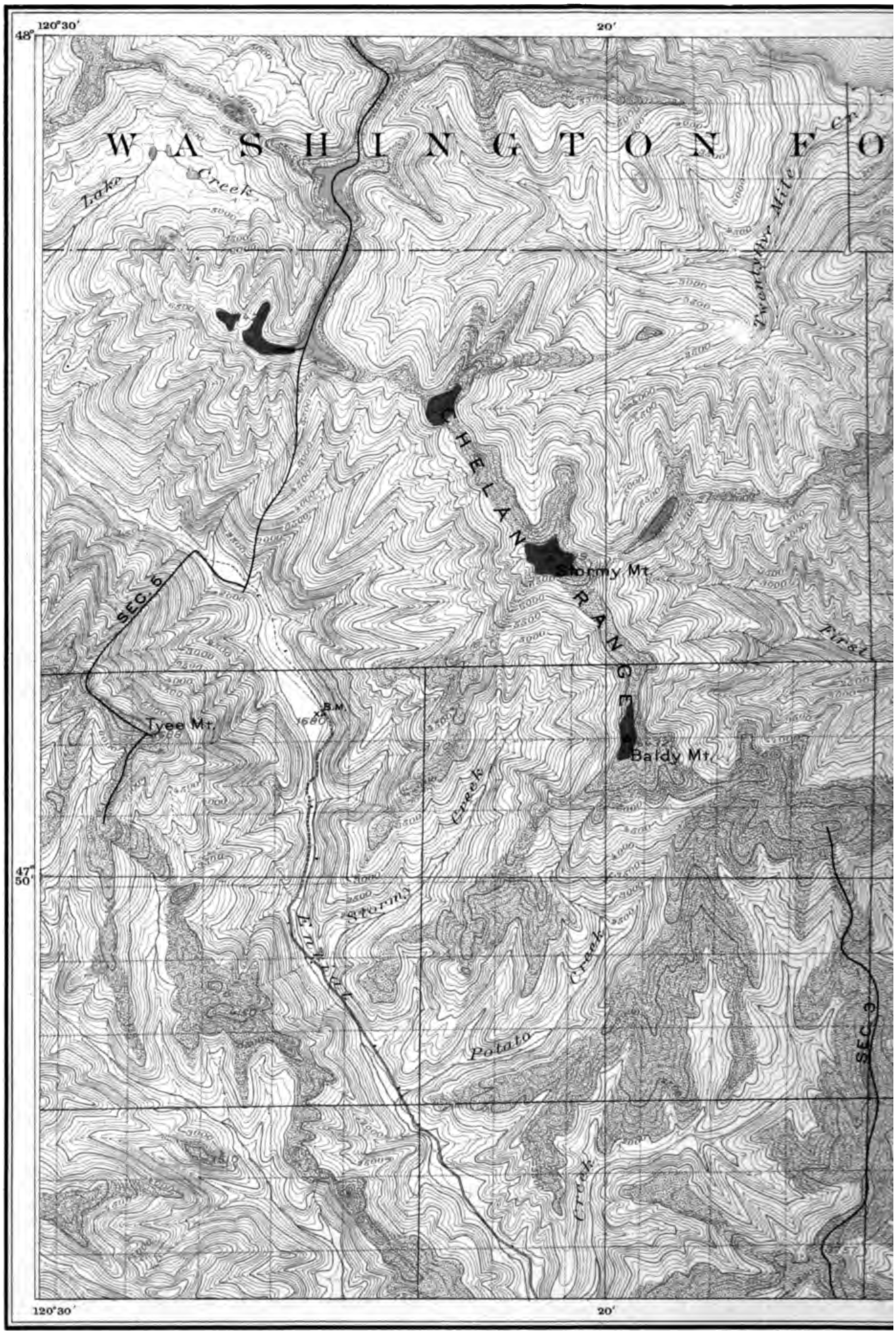

R.U Goode, Geographer in charge
Triangulation by W. T. Griswold
Topography by R.A Farmer and W.T Griswold
Surveyed in 1897-98

PHYSIOGRAPHIC MAP OF THE NORTHE
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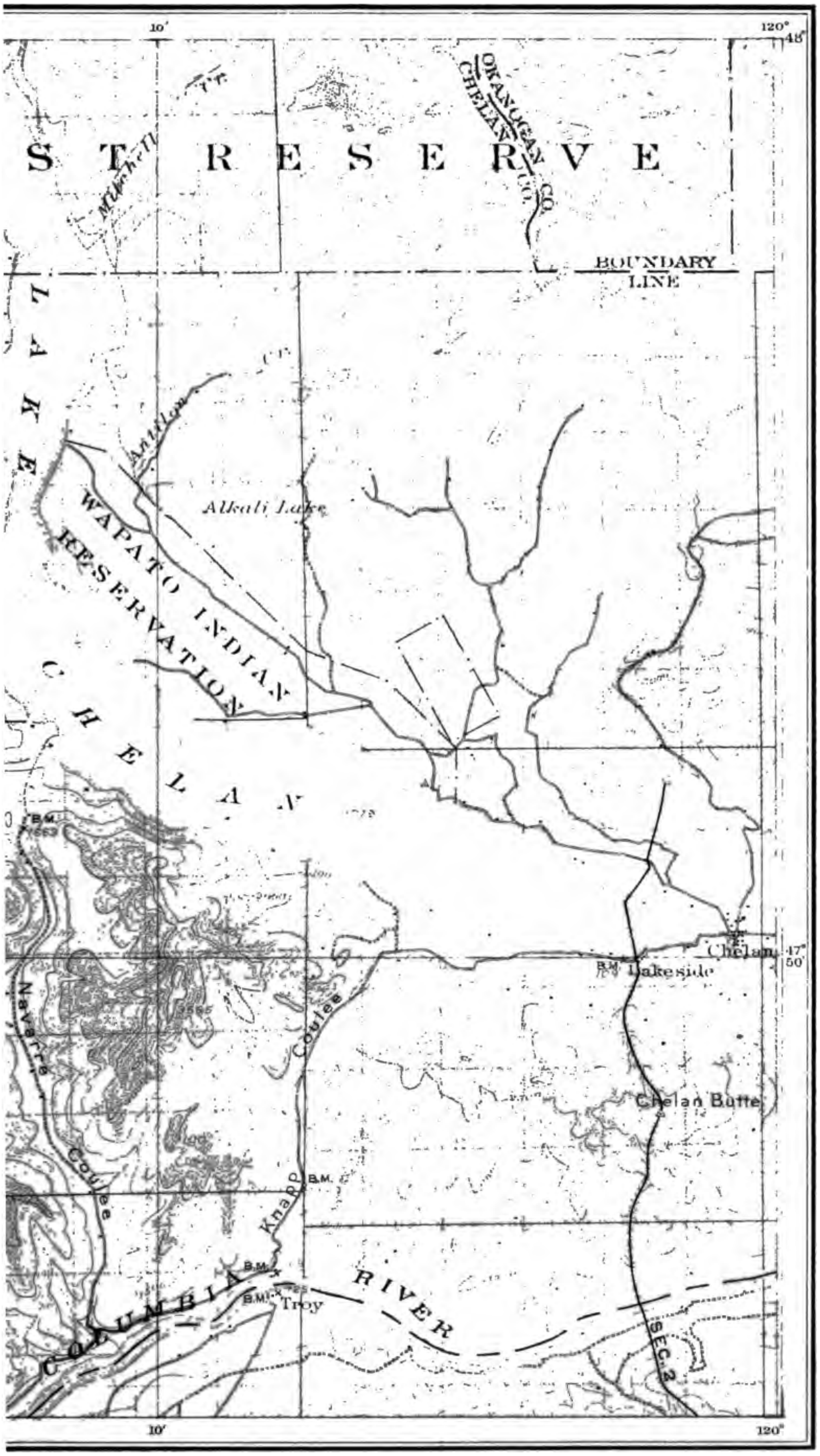

LEGEND

■ Monadnocks on the Methow plain

□ Areas which in form and altitude accord nearly with the Methow plain

□ Areas which in form and altitude accord nearly with features of the Entiat stage

□ Areas which exhibit features of the Twisp and later stages

Sec. 3 Numbers refer to sections on Pl. XIX

F THE CHELAN QUADRANGLE
HELAN, AND THE EASTERN
THE CHELAN RANGE

Physiography by
Bailey Willis, Geologist

4 miles

from the head of a tributary of the Yakima across spurs of the range. The other is a view down Stehekin Valley to the distant Methow Mountains. In neither case does the photograph give the full effect of these landscapes; the angle is but 50 degrees of the full circle, of which the greater part may in a central situation show similar effects, and in each of these particular cases the camera was 1,000 feet or more below the peaks, which consequently appear higher near by. To see such a surface of common altitude the eye should be in it. A diagrammatic presentation of the fact of nearly uniform altitudes is given in the profiles of the Methow Mountains west of Navarre Peaks. (Figs. 4 and 5 of Pl. XIX.) Of the dozen or more summits represented in as many miles, none is lower than 7,800 feet and only one, Star Peak, rises to 8,500 feet above sea. While this diagram gives but a single line, several profiles across the range might be constructed showing similar relations of mountain tops on spurs which extend 3 to 4 miles from the central divide.

The fact of uniformity of summit level becomes more and more impressive as it is observed over wider and wider areas. Russell and the writer have found it to extend over practically all of the high Cascades, occurring at altitudes which vary from 6,000 to 8,500 feet according to the portion of the range in view. There will probably be little if any dissent among future observers from the inference that this widespread equality of heights is derived from a landscape of gentle relief, but opinions will differ as to the degree of plainness of the ancient surface. The occurrence of granite monadnocks, such as Mount Stuart, rising a few hundred feet above the probable position of the old plain, is significant in this connection. Were they numerous they would indicate a hilly region, but far apart as they are and of moderate altitude they suggest that planation had made general progress toward a low peneplain.

The present altitude, which the plain would have above the mountain tops if it existed, is yet to be carefully estimated. In that portion of the Methow Range which has been topographically mapped and studied, the summits near and above 8,500 feet (Star Peak, 8,500; Oval Peak, 8,800) have broad, rounded forms. It is possible that they rose to, if not above, the Cascade plain in this vicinity. On the assumption that the altitude of the plain would now be about 8,500 feet, the inherited summits lie 200 to 600 feet below it. This is probably a minimum. On the other hand, if Mount Stuart and similar granite cones are monadnocks, the plain can not well be reconstructed more than 1,200 feet above the ridges which surround them.

ENTIAT STAGE.

PHYSIOGRAPHIC RELATIONS.

The physiographic relations which constitute the chief criteria that serve to identify features of the Entiat stage are those of a development intermediate between an older and a younger stage. In position and in form Entiat residuals lie between the flats of the Methow plain and the canyons of the Twisp stage.

The Entiat stage was first recognized by the writer in riding from Wenatchee up the Columbia gorge and over the high spurs between it and Entiat River. It then became evident that the Columbia Valley consisted of at least two parts, an inner canyon and an outer valley, a younger and an older phase; and above the older were found the surfaces identified as parts of the Methow plain. In extending the observations it was found that a distinction must be made between those parts of the Cascades which had been subject to much precipitation and consequently had suffered deep corrasion, and those which had received slight precipitation and had been but faintly engraved. This difference of sculptures in Entiat time is parallel with the present diverse aspects of corresponding areas of great and little rainfall.

The criteria by which Entiat and Methow features are distinguished have already been stated. Where they both occur adjacently, the former lie below the latter and in unsympathetic relations. The distinguishing point between Entiat and Twisp slopes is a more or less prominent projecting angle or bench. Its significance depends upon the fact that in homogeneous material normal profiles of a continuous cycle are concave upward. The curve or angle which is convex upward or outward may result from rock differences or from glaciation or from revival of stream activity; the first is commonly a local, the others general phenomenon of any particular district. Along the western side of the Columbia the gneiss and granite are unlike in detail, but in general they are homogeneous in their attitude toward erosion agencies. The hills have not been glaciated, nor did glaciers of the latest epoch extend so far down either the Columbia or Entiat. Nevertheless, each of the long spurs of the Entiat and Chelan mountains is characterized by a markedly prominent angle, and in the ravines a corresponding change occurs at the top of a steep stream grade or fall. In all the unglaciated heights west of the Columbia, this angle is a prominent and significant feature. In glaciated slopes the older records cut by the streams are modified by ice work, and the features are more complex.

DISTRIBUTION AND CHARACTER OF RESIDUALS.

Features such as are characteristic of the Entiat stage exist generally throughout the higher Cascades, so far as the writer's observation goes, but residuals, in the sense of unmodified forms, probably do not survive to the same extent as do those of the Methow stage, if at all. This follows from the greater effectiveness of erosion on slopes as compared with that on plains.

Representative Entiat features are rounded or flat ridges, spurs, and gentle slopes, commonly distinguished by a covering of deep soil, as well as by their physiographic relations. To enumerate them would be to repeat much that has been said in describing the ranges, but typical examples may be cited. In the eastern end of the Entiat Mountains the spurs, which extend at about 4,700 feet from the flat of

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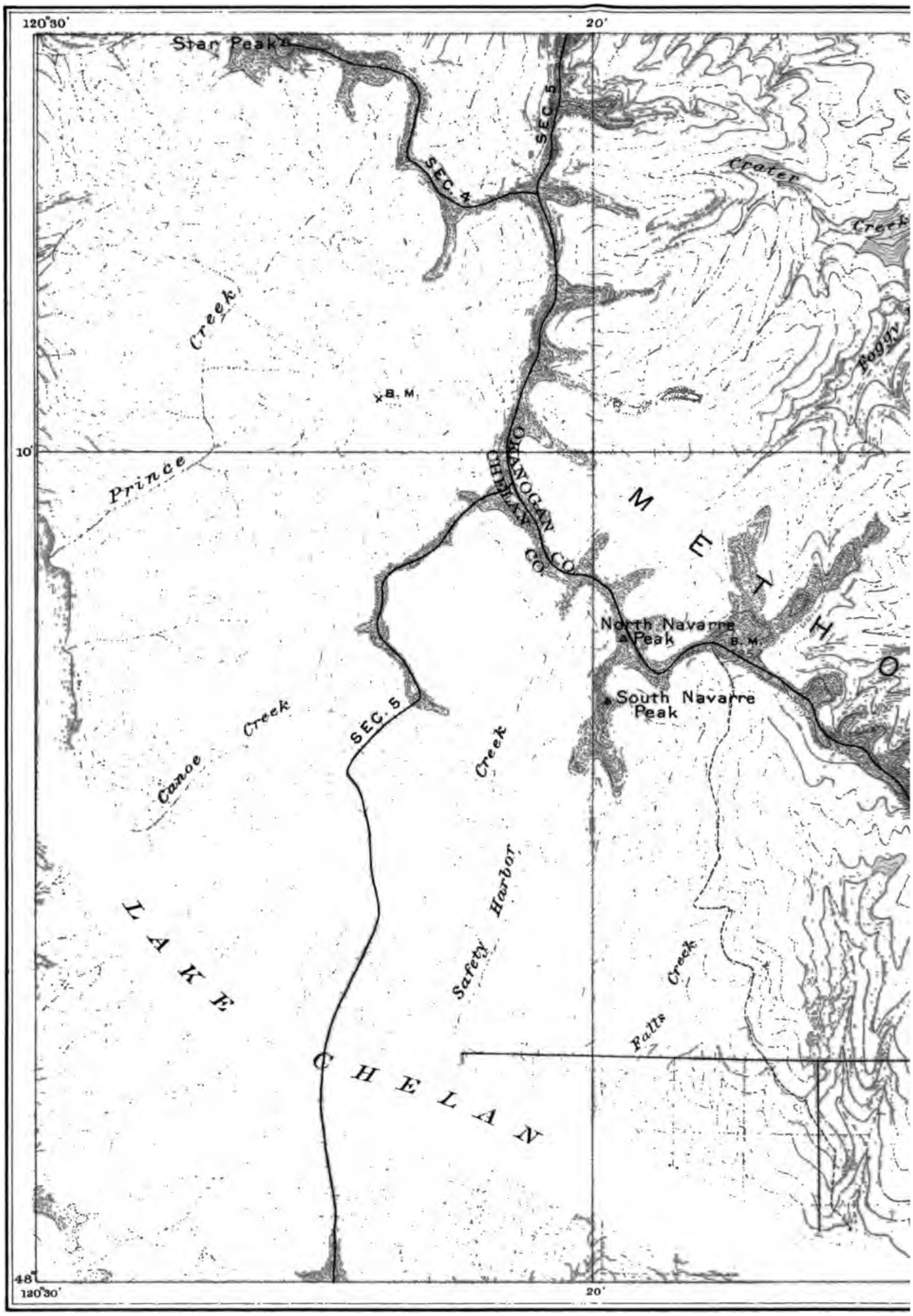

R U Goode, Geographer in charge
Triangulation by A.H Sylvester
Topography by W.T Griswold and R.A.Farmer
Surveyed in 1897 and 1899

PHYSIOGRAPHIC MAP OF THE SOUTHERN
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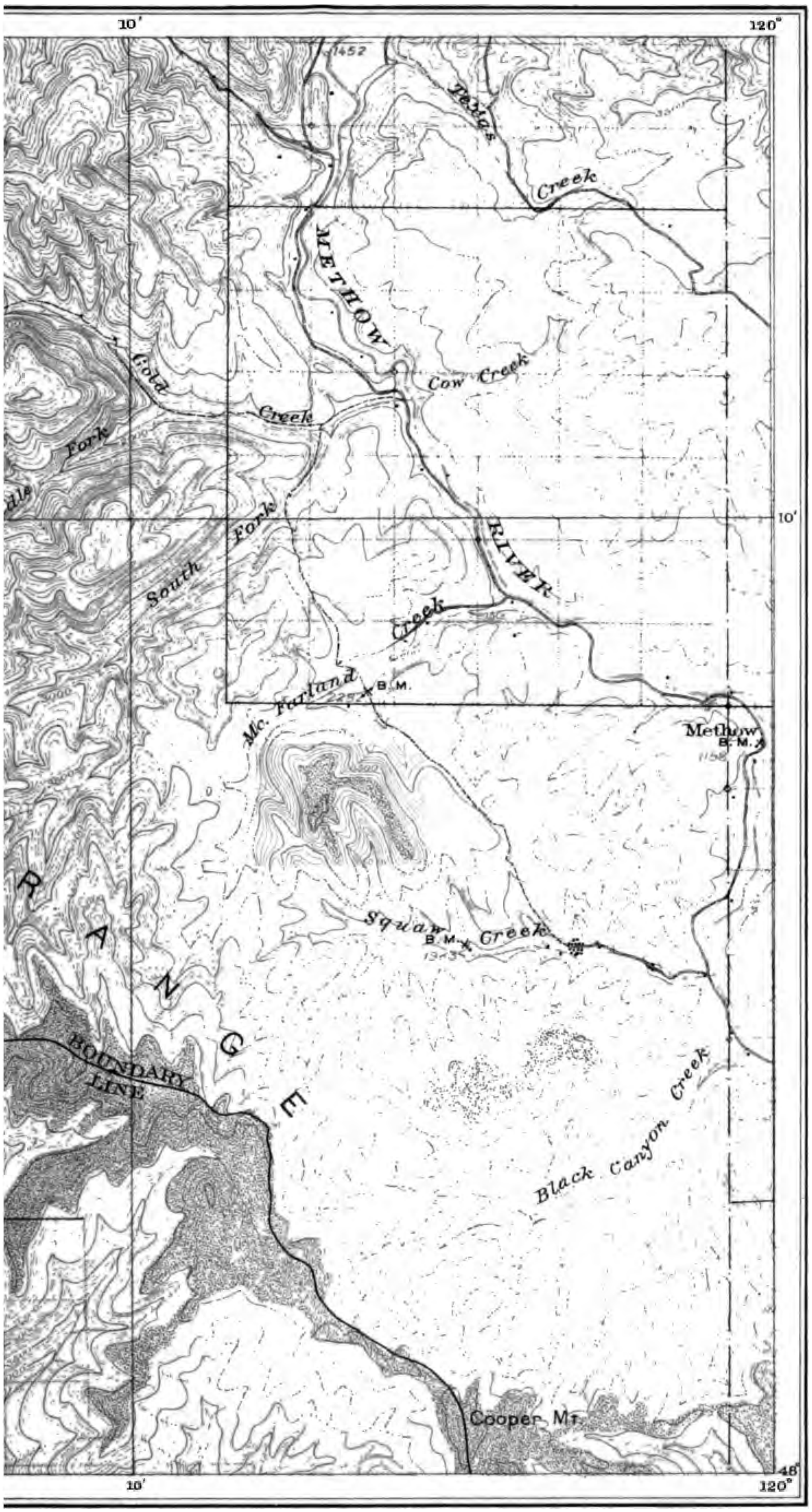


LEGEND

▒ Areas which in form and altitude accord nearly with features of the Entiat stage

▨ Areas which exhibit features of the Twisp and later stages

Sec. 4

Numbers refer to sections on PL XIX

Note: *The valley of Methow River is modified by glaciation to such an extent that inferences can not be safely drawn from the map. As field observations ended with the Methow Range, the valley is not included in the areas interpreted*

THE METHOW QUADRANGLE

ETHOW RANGE,

Physiography by
Bailey Willis, Geologist

4 miles

Methow date down to about the contour of 2,600 feet, exhibit typical Entiat profiles. (See profile 1, Pl. XIX). The ridge isolated by Lake Chelan, Columbia River, and Knapp Coulee is a characteristic Entiat form in its summits and spurs above the 1,500-foot contour. (See profile 2, Pl. XIX.) The rocky height of Chelan Butte is probably a monadnock of pre-Methow date, but the development of Entiat features has gone so far as to remove the plain from about it. The slopes of the ridge are scored by numerous ravines, in which corrasion has progressed steadily during all the time since the Entiat epoch closed. They are therefore more deeply cut than formerly, having steeper grades toward the top. In their lower channels they have been materially modified by deposits of the Chelan glacial epoch.

The profile 3, Pl. XIX, exhibits Entiat slopes in relation to the forms that preceded and followed them. The long spur between Mad Creek and Tyee Mountain, 3,500 feet to 6,500 feet; the spur of the Chelan Mountains, 5,500 feet to 6,700 feet, and those of the Methow Mountains above 6,000 feet, along this section line, are reasonably near Entiat features. They exhibit the long concave curve, the windgaps, and the rounded summits, for the most part deeply soil covered.

There may be features whose age is indeterminate because their aspects and relations are capable of more than one interpretation. Such a one is the flat spur contoured by the 3,000-foot line west of Navarre Coulee and rising by gentle grade to the mountain which has an altitude of 3,757 feet. If of Methow date, it is a part of the plain marked out around the last-mentioned mountain near the 3,500-foot contour, and its inferior position is due to warping. If of Entiat date it is a low level of an early epoch in the widening of Navarre Valley; and in that case, also, it may, in consequence of warping, now occupy a position lower than it had in relation to the Chelan Mountains. Were the ridge continuously broad and gentle of slope from the mountain having an elevation of 3,757 feet nearly to the top of the Chelan Mountains east of Baldy, the former date would seem probable; but the hill crowned by the 3,500-foot contour and several interruptions of the gradual slope by steeper intervals indicate that the plain was eroded, and we have to deal with an Entiat surface which locally developed a flat feature.

DEGREE OF ENTIAT RELIEF.

West of the Columbia the differences of elevation covered by features assigned to the Entiat stage are considerable: In the eastern portion of the Entiat Mountains, from 2,600 feet to 4,700 feet; in Chelan Butte, from 1,600 feet to 3,700 feet; in the district west of Navarre Coulee, from 2,000 to 6,000 feet; in Tyee Mountain, from 3,500 to 6,600 feet; in profile across Lake Chelan from Fourmile Ridge to the Methow Mountains, from 6,000 to 7,700. These variations occur not only in different places, but on slopes which decline in different directions, and some part of the apparent relief is attributed to deformation. We may therefore distinguish between those which apparently have not and those which have been tilted.

The spur which descends at the eastern end of the Entiat Mountains connects a well-preserved Cascade flat with the gorge of the Columbia, the largest stream. Lying on but parallel to an axis of uplift, its inclination has not been affected appreciably by warping, and its relief—2,100 feet—may fairly be taken as representing the facts at that place in Entiat time. The spurs of the Chelan Mountains extending north from Fourmile Ridge and those of the Methow Mountains opposite them are apparently once continuous parts of a profile now interrupted by Chelan Canyon. They do not exhibit evidence of depression or tilting toward the canyon, and their degree of relief—1,700 feet—is probably not greatly different from what was the maximum in Entiat time at that point.

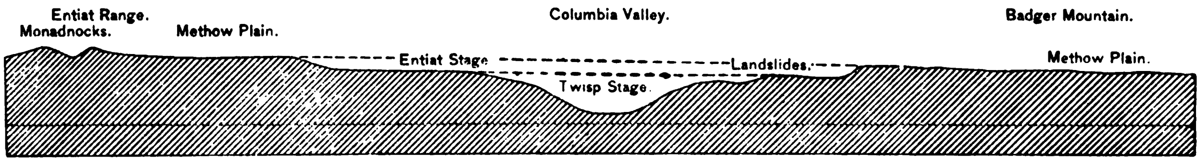
The long slopes which rise 3,000 feet and more to Tyee Mountain and to the Stormy Mountain ridge are apparently not in their original attitude. The elevations of Cascade residuals and the canyons cut in these ranges show that the heights of Tyee and Stormy are due in part to local as well as to general uplift, and that the Entiat features have shared in the change of attitude. In a less degree this is believed to be true also of the Chelan Butte ridge.

GLACIATED ASPECTS OF ENTIAT HEIGHTS.

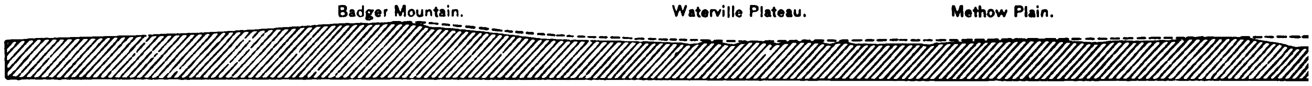
Where extended masses occur at high altitudes in the Cascade Range, the togographic features may be classed as four in number: (1) Dominant peaks, usually acute in form; (2) high serrate ridges and spurs, which are often very narrow; (3) elevated amphitheaters of characteristic glaciated form; (4) canyons, usually also glaciated. Those dominant peaks which rise approximately to a common altitude or higher are considered to be descendants of the Methow plain and its monadnocks, as already stated. Similarly, but even less adequately, the serrate ridges and glacial amphitheaters represent features of the Entiat stage. They are developed in masses which were not deeply cut by canyons of the Twisp stage, but those masses may probably have been sculptured into valleys and divides during the Entiat stage. The alternative is to assume that degradation of the Methow plain to post-Chelan aspects of glacial sculpture was accomplished without any intermediate stage of aqueous erosion. This view possibly might resonably be held were not the Entiat stage clearly recognizable in the unglaciated area. Since the latter is the case, however, it is logical to infer the development of valleys and ridges of Entiat date, from which glaciated amphitheaters and their tangent arêtes are derived.

MATURITY OF ENTIAT TOPOGRAPHY.

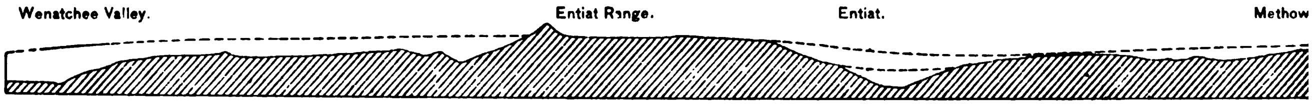
In the usual threefold division of a topographic life period into youth, maturity, and old age, maturity may be used in either one of two senses, namely, to describe



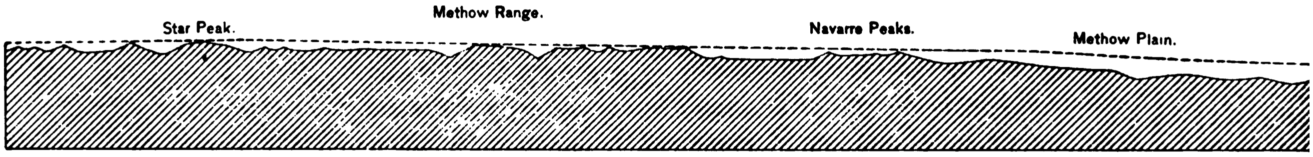
1. PROFILE ACROSS THE COLUMBIA VALLEY ALONG THE ENTIAT-BADGER MOUNTAIN FROM WEST BY NORTH TO EAST BY SOUTH.



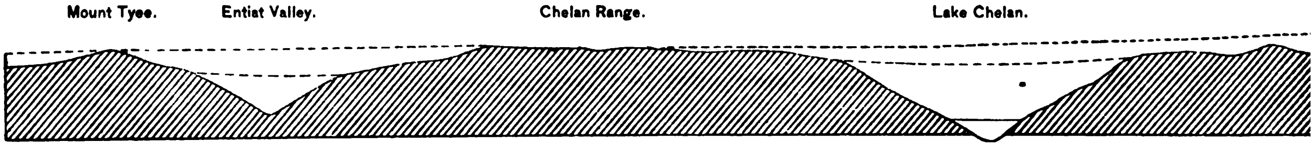
2. PROFILE ACROSS THE BADGER MOUNTAIN UPWARP, THE WATERVILLE DOWNWARP, AND THE CHELAN UPW



3. PROFILE FROM WENATCHEE VALLEY TO CHELAN RANGE ACROSS THE ENTIAT UPWARP AND THE WATERVILLE DOWNWARP TO THE ALTITUDE OF THE METHOW PLAIN FROM SOUTH BY EAST TO NORTH BY WEST.



4. PROFILE ALONG THE CREST OF THE METHOW RANGE FROM NORTHWEST TO SOUTHEAST, I

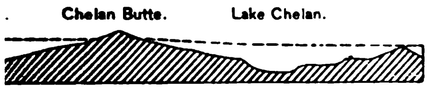


5. PROFILE ACROSS THE CHELAN AND METHOW

PHYSIOGRAPHIC PROFILES
WENATCHEE-CHELAN DISTRICT
CASCADE RANGE

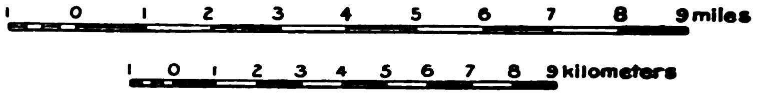
By Bailey Willis

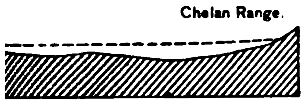
Deduced from United States Geological Survey
Topographic Maps and Field Observations



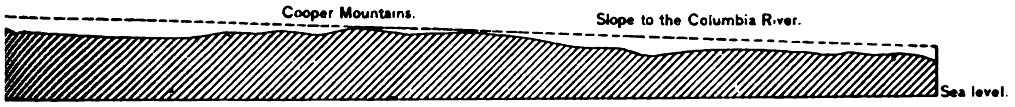
OUTH TO NORTH.

VERTICAL AND HORIZONTAL SCALE

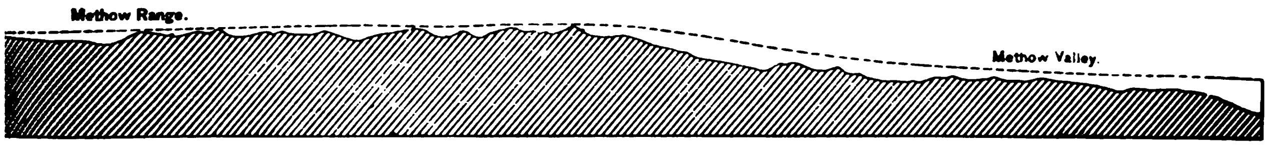




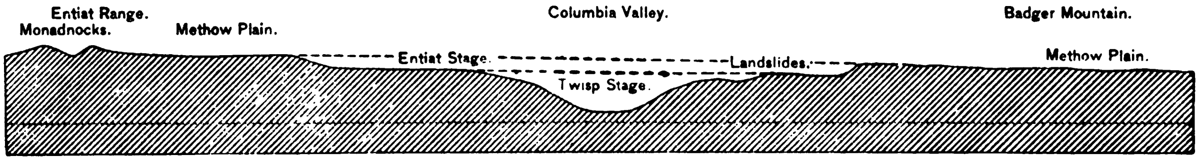
ᴾWARP, AS SHOWN BY THE



FEATURES ENTIAT STAGE CUT IN THE METHOW PLAIN.



FROM SOUTH BY WEST TO NORTH BY EAST.



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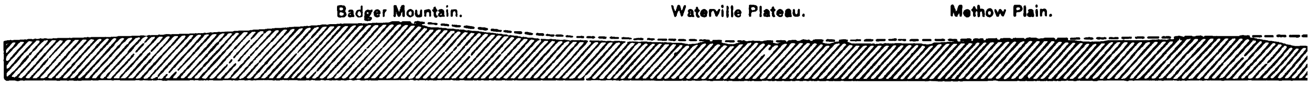

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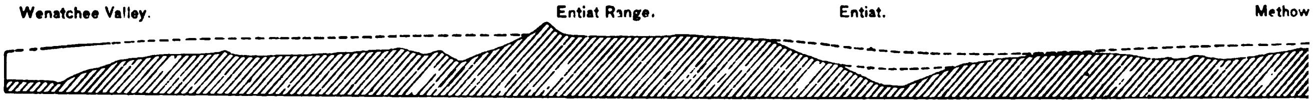

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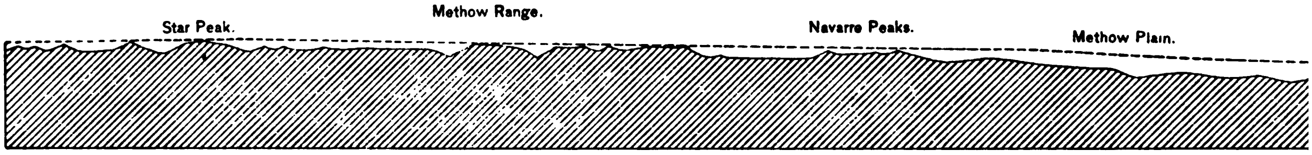
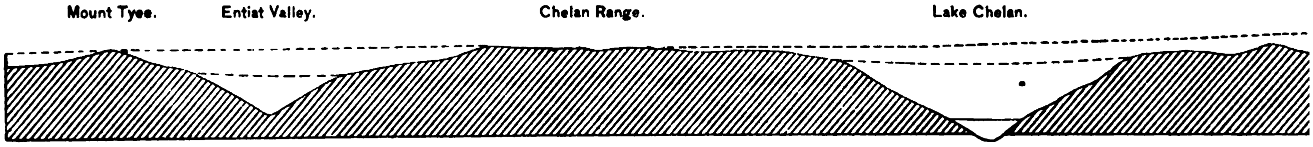


4. PROFILE ALONG THE CREST OF THE METHOW RANGE FROM NORTHWEST TO SOUTHEAST,



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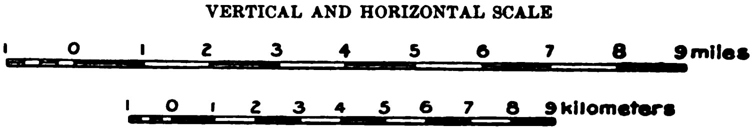
VERTICAL AND HORIZONTAL SCALE
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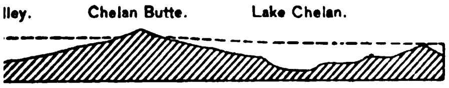
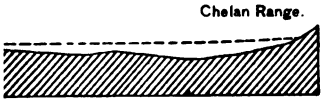
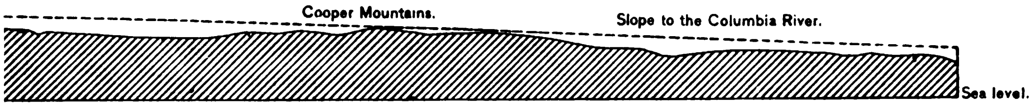


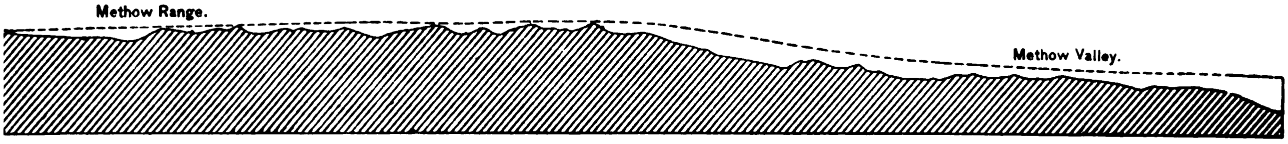
SOUTH TO NORTH.



UPWARP, AS SHOWN BY THE



G FEATURES ENTIAT STAGE CUT IN THE METHOW PLAIN.



S FROM SOUTH BY WEST TO NORTH BY EAST.

a long mid-interval during which the prevailing features are narrow divides, steep slopes, and V valleys; or, second, to designate with precision that exact date at which a given residual of an earlier stage is reduced to nothing and the divide begins to dwindle under the attack of opposed headwaters. In the latter sense maturity at any particular date is a term of strictly local application, since residuals do not all succumb at one time.

In the broader sense of the word, Entiat topography was mature where precipitation was heavy. In the narrower sense, it approached maturity about residuals of the Methow plain, where they still exist, but generally outside the arid region it had passed the precise instant of mature development. That is to say, the divides had become sharp and lower than the corresponding surface of the Methow plain.

ENTIAT FEATURES IN ARID AREAS.

In arid areas Entiat features have not been clearly recognized. This fact may be due to one of two conditions. In Entiat time areas now arid and high may have been similarly situated, or they may have been low. In the one case aridity, in the other lowness, would have limited erosion, and the features which developed would in either case be inconspicuous.

In the Yakima district G. O. Smith does not distinguish the Entiat stage. On the Waterville plateau and Badger Mountain it is probable that Entiat features exist, but are mantled by later deposits and obscured. The valley of the Columbia bounds these areas on the west. Its inner and outer gorges are less conspicuously separate east of the river than west of it, because landslides have generally modified the scarp, and to them the suggestive details of the profile might be ascribed; but the two episodes of development are distinguishable on the east in appropriate relations to the corresponding details west of the river. On the plateau there occur, below residual flats of Methow date, long spurs separated by lightly engraved channels. Their contours and profiles are round and gentle. They appear nowhere to be composed superficially of hard rock. Soil derived from basalt and a soft sand deposit of unknown age and origin were the materials seen. Well-filled angles and fluent curves of the landscape evidence wind work. The sculpture is that of aqueous erosion, moderately developed, and later modified by wind erosion and wind-drifted material.

In view of the stages elsewhere found, it is probable that the work of aqueous agencies was accomplished during the Entiat and Twisp epochs, and that effects of mantling are due to conditions which prevailed during the Chelan and Stehekin (Glacial and post-Glacial) stages.

On Badger Mountain ravines are cut more deeply than on the plateau and winds have had comparatively little effect; yet the slopes of the mountain exhibit remarkably slight erosion as compared with the heights west of the Columbia. It will be shown in discussing deformation that the elevation of Badger Mountain above Waterville plateau is chiefly a growth of post-Entiat date, and therefore Entiat features are inconspicuous on the mountain, and what dissection has occurred there is of Twisp age and later.

TWISP STAGE.

CHARACTERISTIC FEATURES.

Canyons are the prevailing valley forms of the Cascade province. In elevated districts they are profound and numerous, and, having the U section due to glaciation, their volume represents a large part of that of the original uplifted mass. Between the glaciated and arid districts lies the zone of simple but energetic aqueous erosion in which unmodified canyons are most strikingly developed. In the arid region, the central plateau of Washington, canyons are deeply cut in the basalt. The most conspicuous, such as Grand Coulee, are ascribed to diversion of the Columbia during glacial time, and if that be true, do not belong to the stage here to be discussed.

The inner gorge of the Columbia between Wenatchee and Methow is a steep-sided channel cut below older topographic features in the bed rock mass of the region. Its position and proportions are such in relation to the river that there can be no doubt that the master stream cut it out. Glacial striæ were found by Salisbury on its western wall just above Chelan Ferry. A morainic terrace occurs on the eastern bank a mile below Chelan Falls, and from this southern limit of the glacier a very conspicuous system of river terraces, composed of glacial drift, extends down the valley. The gorge is, therefore, of aqueous origin and was carved prior to the latest glacial episode. As such it is a representative canyon of a pre-Glacial stage. It lies within and clearly distinct from features ascribed to the Entiat stage, and its development thus occupies an interval of time between the Entiat epoch and glaciation.

A geographic name for this stage can not well be chosen from this typical section of the Columbia Gorge, the desirable names having been applied to other uses, but it would appear from the topographic map of the Methow quadrangle that Twisp River has worked out a channel scarcely less characteristic, and the name is selected accordingly.

DEVELOPMENT OF TOPOGRAPHIC FORMS.

The Twisp cycle of topographic development was interrupted at an early phase by the advent of glacial conditions. The survival of Entiat and Methow residuals and the effects of glaciation sufficiently demonstrate this fact.

Columbia Canyon, between Wenatchee and Chelan, was cut to its present depth by aqueous corrasion before the latest Glacial epoch, since it is occupied by drift, which the river has removed down to bed rock at various points along its channel. The canyon walls receded to some extent during Glacial and post-Glacial time, and the amount of recession is shown to be appreciable by the fact that cliffs above Chelan Falls, past which a glacier extended and over which it rose, now exhibit pinnacled profiles that have developed since the ice withdrew. But the occurrence of glacial striæ near the summit and on the river side of the cliffs indicates that the form of the canyon was not greatly different then from what it now is. This is within less than 2 miles of the end of a tongue of the wide-spreading glacier which came from Methow and Okanogan districts. The ice was probably nearly stagnant and ineffective.

In the glaciated region of the higher Cascades, the canyons are developed on a grand scale. Russell has rightly described them as extending with channels at railroad grades into the very heart of the mountain mass, and they are from 1,000 to 3,000 feet in depth. They have been widened and deepened by ice work, to what degree is yet to be determined, but apparently in some instances greatly. Nevertheless, when all reasonable allowance has been made for glaciation, the canyons which may be ascribed to corrasion during the Twisp stage were of great depth. They were relatively narrower than they now are, and their topographic development had the character of advanced youth.

CHELAN STAGE.

CHARACTER OF THE RECORD.

The climatic conditions of the Chelan stage interrupted the topographic cycle of the Twisp stage. They induced glaciation, and occasioned very pronounced phenomena of glacial erosion and glacial construction, the latter including extensive deposits from overloaded streams. Russell has already described these features in a preliminary way, and they have been touched upon incidentally in this article. The general facts are conspicuous, have been widely observed, and are published. It is expedient here to discuss only one fact, the depth of Lake Chelan, which has a possible relation also to the question of deformation.

THE BASIN OF LAKE CHELAN.

Lake Chelan occupies a canyon in granitic and gneissoid rocks. The waters are retained by a dam of drift, but discharge through the gorge of Chelan River into the Columbia, whose bed is not far from solid rock. According to the altitudes above sea of rock in place in the Columbia several miles below the junction, that of the lowest rock sill over which the waters of Lake Chelan can have escaped is about 700 feet. The elevation of the lake's surface is 1,079 feet, and its depth exceeds 1,000 feet through a stretch of 16 miles.[a] The maximum sounding was 1,419 feet, i. e., to 340 feet below sea level, or 1,040 feet below the rock rim of the basin. The depths are given on the map (Pl. XVII), and they present an interesting problem in the question, How did the lake channel become so deep?

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[a] Sounded by Mr. W. G. Steel, at request of Mr. Henry Gannett, for the United States Geological Survey. MS. records.

According to the physiographic record, the Chelan channel developed by stream robbing and became a river canyon through the usual effects of stream action, which are, however, incompetent to have so greatly deepened it. It may have been deepened by faulting or glacial erosion.

Faulting is not readily capable of direct proof or disproof in the rock structures of gneiss and granite. There is, however, throughout the Chelan-Stehekin system of channels a unity of form, which strongly suggests unity of development, and through which any hypothesis of faulting as a condition of the Lake Chelan canyon should be extended to its tributaries; but the ramifications of the system and the slenderness of the supposed downthrows are such that the hypothesis is untenable. If the area of faulting be restricted to that of excessive depth in the Chelan Basin, there is a similar peculiarity of form in the supposed downthrow and no evidence to support the proposition. We may turn, then, from the purely theoretical idea of faulting to that of glacial erosion.

Effects of glacial erosion are obvious throughout the Chelan-Stehekin system. They may be traced from the moraines of existing glaciers in the cirques about the headwaters, down the grooved and rounded canyon walls, into the waters of Lake Chelan, and out to the terminal moraine near the Columbia, in all a distance of 70 miles. Three miles above the terminus of the ancient glacier its thickness was 1,000 feet, and its surface stood about this amount above the present level of Lake Chelan. Thirty miles above its lower end, that is, near Safety Harbor Creek, the thickness of the ice was 4,500 feet, and toward the head of the lake it probably exceeded 5,000 feet. Detailed observations as to the upper limit of glaciation along the lake shore are needed, but the above statements are based upon a few points definitely noted. That this mass of ice was capable of exerting great erosive power can scarcely be doubted, but it remains to be shown that the phenomena of depth of the lake basin bear some logical relation to the probable effects of ice corrasion.

It is believed that the erosive power of ice when moving as a glacier is a function of the volume of ice, the restriction of channel, and the rate of flow.[a] These factors are, it is true, in a measure interdependent, but it is not important here to separate their influences, as we can not deal with the problem quantitatively. It will suffice to show that the excavation of the channel is proportioned to the amount of ice entering from successive tributaries and that, where the volume is constant, the depth of the channel is inversely as its width.

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[a] Personal communication with G. K. Gilbert.

The extent of former glaciers in the Chelan-Stehekin system is indicated (with a rough approximation only to the facts, but sufficient for this purpose) in the map (Pl. VIII). It may there be noted that the drainage from a considerable area is concentrated at the junction of Stehekin and Bridge creeks, and it is at that point that the headwater canyons pass into a conspicuously wider channel, and that the stream assumes a flatter grade. Just above the junction of Agnes Creek this flat ends in an abrupt descent to a wider and lower valley floor, which extends from Agnes Creek to the head of Lake Chelan. The cross section of the canyon widens slightly, but not notably, and its depth, so far as it may be determined by the soundings in Lake Chelan, increases gradually to the junction of Railroad Creek. Abreast of this stream the valley is considerably wider, and may be regarded as a basin competent to store a considerable volume of ice. A short distance down the lake, near Prince Creek, is the upper end of the Narrows, which extend to Twentyfive Mile Creek. Here the walls of the canyon are steepest, and approach each other most nearly, and here the depth of the lake increases rapidly. Below Twentyfive Mile Creek the valley opens out and the lake basin rapidly shallows.

There is in the above-described relations that coincidence between width and depth of channel which in the single case might be considered fortuitous, but which, when oft repeated and found to be systematic, presents a strong argument for a relation between cause and effect. While the data are by no means so complete as might be wished, and while a thorough discussion of the problem would require that one should eliminate the effects of glacial and stream filling in order to arrive at a true measure of the depth of the channel, it is not probable that these subordinate factors could change the dominant relations from which it is inferred that the basin of Lake Chelan owes its unusual depth and character chiefly to glacial erosion.

A further test of this conclusion may be applied by contrasting it with other valleys in the same region, many of which have been occupied by glaciers, and none of which exhibit similar peculiarities. A thorough study of the glacial effects throughout the region should shed much light upon the nature of the phenomena, but it may here suffice to say that the Chelan case is exceptional (1) in the large volume of ice contributed from an area of approximately 350 square miles, throughout which the mountain summits range in altitude from 7,000 to 8,500 feet, and (2) in the remarkable depth and narrowness of the canyon through which the glacier was forced.

DEFORMATION.

Criteria.—The criteria according to which the nature and amount of deformation are commonly determined are of a stratigraphic character. The surface of a stratum, assumed to have been plane and observed to be flexed, is a datum from which changes of form may be deduced. In the area under discussion in the present case the rocks are gneisses and intrusive granites, whose structures do not afford dips from which to infer the nature of recent deformation. The occurrences of basalts, which do afford such data in the Ellensburg district, are of no value in the area west of the Columbia and north of the Wenatchee, as their distribution is very limited. Jointing, the commonly developed structure of all the rocks of the district, has not been so studied as to yield results. It follows that deformation must be investigated upon a different basis, viz, chiefly upon physiographic evidence, through the warped form of the earliest recognized topographic surface, the Methow plain; and the facts described in the account of the physiographic history are thus made use of in the following discussion.

Fundamental propositions.—In the preceding discussion certain principles have been applied in interpreting the relations of physiographic features and deformation, but the statement of those principles has been deferred to this place, where it may form an introduction to the account of mountain growth. In general terms the propositions are as follows:

(1) Mountain growth involves changes of altitude of such vertical amount and such moderate extent as compared with continental areas that elongation of the earth's radii beneath the mountain mass may more plausibly be assumed to account for the elevation reached above sea level than general subsidence of the datum plane. The effect of such elongation is appropriately described as an uplift when the whole mass is considered.

(2) Uplift results in deformation of the preexisting topographic surface, which is elevated in some areas above others that may be considered relatively depressed. In what follows the term warp will be used to designate deformation of the surface, upwarp and downwarp being employed to describe, respectively, elevated and depressed areas, always the former topographic surface, and independently of the rock structure. The latter is appropriately expressed in the terms anticline and syncline.

(3) Erosion occurs only as a result of change of relative altitude, and its effects are a function of the amount of change.

(4) Other things being equal, the several sections of a river valley between source and mouth are consistently developed, when uplift has been uniform and simultaneous, within moderate limits of variation. Inconsistent sections are evidence of unequal uplift or of uplifts of different dates.

(5) At any particular stage of development in homogeneous rocks the normal grade, or slope, of a plain or river valley is variable within narrow limits only; abnormally steep, gentle, or reversed grades are effects of warping during succeeding cycles.

CASCADE UPLIFT.

The Cascade Range is an elevated mass which is observed by all who come within sight. Equally recognizable by adequate observation is the wide, tabular form of its surface, as are also the marginal slopes which connect it with lower adjacent surfaces. The gross form, all details of spurs and sculpture being omitted from consideration, is that of a broad uplift, with wide, flat top and sloping flanks.

The general fact that the uplifted surface has been eroded is obvious, and investigation of the topographic forms shows that they express several stages of development, of which the initial one was an ancient peneplain that extends over the mountain mass. The peneplain having been practically flat and low, according to its origin, and being now elevated in part, there has been warping, the amount and character of which are expressed in any section by the difference between an arc of the earth's spheroid at sea level and the flat arch of the uplifted surface. Thus we may describe the Cascade uplift as that broad and flat-topped elevation which lies between Puget Sound on the west and the central plateau of the Columbia River Valley on the east.

Height and extent.—With reference to sea level, the surface of the Cascade uplift, or the upwarp, actual and restored, varies in altitude from 6,000 to 8,500 feet throughout the area of its upper level. The maximum of 8,500 feet is attained probably north of the forty-seventh parallel and is maintained throughout more than one degree of latitude to the forty-ninth parallel. South of the forty-seventh parallel the extent and altitude of the warped plain are not well known, except that at an altitude of about 7,500 feet it forms the platform upon which stands the volcanic cone of Mount Rainier, and probably extends in a similar manner beneath Mount Adams, Mount Hood, and other volcanoes in Oregon. Its altitude probably lessens toward the south, but it is not likely that it falls below 5,000 feet along the broad axis of the uplift. The width of the uplift at its elevated plateau level is variable, but is probably rarely less than 60 miles nor more than 100. As may be seen in Pl. I, the eastern margin is crenulated, and in consequence of the fluting the width of the flat top of the upwarp is very variable, and it is possible, as suggested by Smith, that the larger marginal downwarp may extend nearly across the axis or entirely across it.

The further description is limited to the area north of the forty-seventh parallel and more narrowly to the regions which have been described in detail in the preceding chapters.

Limits of Cascade upwarp.—The limits of an upwarp are here taken to be represented by those slopes produced by warping, by which the descent from the high, flat top to adjacent areas is accomplished, without regard to effects of erosion.

In this sense the Cascade upwarp is limited on the north, according to the observations of G. O. Smith, apparently by a slope which extends across the axis of the range a short distance north of the forty-ninth parallel and leads down to a lower surface south of the Frazer River, but still high above the canyon of that stream. On the west, south of the forty-ninth parallel, according to Smith, the plateau of the upwarp extends, at an elevation of 5,000 feet, under Mount Baker, and thence descends to the Sound level by a monoclinal flexure. A degree of latitude farther south, northeast of Seattle, its western margin lies farther east. In the vicinity of Index, on the Great Northern, at the town of Snoqualmie, and along Green and White rivers, north of Mount Rainier, the descent from the mountain summits, at elevations of 6,000 to 7,000 feet, to that of the gravel plateau of the Puget Sound Basin is so abrupt as to suggest a fault scarp. There is no positive evidence of a fault as yet known, and the alternative hypothesis of glacial erosion has at least equal value at the present time. Beneath Mount Rainier and possibly to some distance west of that peak the upwarp maintains an altitude of 6,000 to 7,000 feet, and it appears in this latitude, just south of the forty-seventh parallel, to attain an expansion comparable to that which it has along the forty-ninth parallel.

The eastern limit of the Cascade upwarp may in general be described as a slope which stretches in a direction south by west from the vicinity of Osoyoos Lake, on the forty-ninth parallel, to Ellensburg, and thence southerly along the west side of Yakima Valley, across the Columbia, into Oregon. This general statement of the position of the slope must, however, be qualified by the description of marginal flutings, which extend nearly at right angles to the major uplift far out into the adjacent plateau on the east and give to the axial upwarp an extremely irregular form.

The area of the upwarp thus described covers approximately 5 square degrees of the surface north of Columbia River, equivalent to about 20,000 square miles. Its further extent in Oregon has not been determined, but it is probable that it is equal to that in Washington.

MARGINAL FLEXURES.

The eastern slope of the Cascade upwarp north of latitude 46° 30′ has been studied physiographically by G. O. Smith and the writer with sufficient care to determine several marginal flexures, whose axes trend, in general, northwest and southeast; that is, nearly at right angles to the broad major axis of the upwarp itself. A statement of these features, so far as they may be described by the writer follows, with a brief account of the evidence according to which each is recognized.

Methow downwarp.—Methow River is one of the larger tributaries of the Columbia, which it enters about midway between the Okanogan and the Chelan, in latitude 48°, longitude 120°. The general trend of the Methow Valley is south by east. Its headwaters are near the forty-ninth parallel, and are opposed to those of Paysayten River, which flow northerly. On the east is the Okanogan Range, and on the west the Methow, both of which are of great altitude. The elevation of the Methow above sea at its junction with the Columbia is 750 feet; at the town of Methow it is 1,158 feet, and at Winthrop, 30 miles from Methow, along the stream, it is 1,765 feet. Winthrop is situated at the principal forks of the river, and above this point the grade of the stream rises more rapidly. The aspect of the valley at the present stream level varies, according to the rocks in which it is carved. A lower section, cut in schists, is narrow and canyon-like; an upper section, comprising most of the stretch between Methow and Winthrop, is excavated in softer Mesozoic rocks, and the valley floor is wider. It has been occupied by a glacier, which has left extensive deposits, especially along the river channel. From those conditions of diversity of rock structure and interaction of stream and ice work, it follows that the physiographic aspects of the valley are not simple, and that it presents a problem in sculpture which can be fully solved only by careful observation on the ground. That observation has not been had, and the inferences which follow are based upon distant views from the Methow Mountains, study of the Methow atlas sheet, and an interpretation consistent with that of phenomena of adjacent regions.

Above the valley bottom of Methow River, between Methow and Winthrop, many hills rise to an altitude of about 4,000 feet above sea, and they are thought to represent a former level, which theoretically may be that of the Methow Valley bottom reached during the Entiat stage or may represent the older Methow peneplain. If the former be the case, the corresponding level of the Methow plain would lie at an altitude above 4,000 feet, an amount which may be deduced from the depth of the Columbia Valley at the close of the Entiat stage. The maximum determined for that valley is about 2,100 feet, as observed in the Entiat Mountains. There is no reason to suppose that the Methow has made any deeper excavation than the Columbia. Indeed, the inference would be rather the other way. Hence the position of the Methow peneplain in the Methow Valley is not far from 6,000 feet above sea, provided the general uniformity of hilltops at 4,000 feet represents the bottom of the Methow Valley in Entiat time. On the other hand, the 4,000-foot level may stand for the Methow plain, and, if so, it would coincide by gradual slope with the general altitude of that plain in the Columbia River Plateau to the southeast.

Whether the level of the Methow peneplain in the Methow Valley be 6,000 or 4,000 feet above sea, it is lower than that of the plain on the adjacent Okanogan and Methow mountains, its place in the former being probably not far from 8,000 feet, and in the latter not less than 8,500 feet above sea. Hence it seems reasonable to regard the Methow Valley as a downwarp resulting from deformation of the Methow plain.

Methow upwarp.—Southwest of the Methow Valley, in latitude 48°, is a great mass of mountains known as the Methow Mountains. In it are sunk the canyons of the Twisp and Lake Chelan, and it extends westward into the highest part of the main Cascade Range. Its area may be estimated at 1,000 to 2,000 square miles, according to the limits which may be arbitrarily drawn between it and the central Cascade upwarp. This mountain mass is designated the Methow upwarp.

The Methow upwarp is defined not only by existing topographic features, but by the altitude of the Methow peneplain and the slopes which it has assumed. In general, where most elevated, the Methow plain has an altitude of 8,500 feet, coincident with the crest of the Methow Mountains. On the east the surface descends from Navarre Peaks to the Methow and Columbia, sloping from a probable altitude of 8,000 feet to that of 3,500 or less. Toward the northeast the surface slopes to the position of the plain in the Methow Valley. On the south the descent is from an altitude of 6,000 feet to that of 3,500 feet. The southern margin is complicated by a much smaller feature, the depression within which lies the lower end of Lake Chelan, and south of which is the uplift forming the Chelan Range. The upwarp of Chelan Mountains is, in fact, a spur of the Methow upwarp, with which it is continuous along Fourmile Ridge and across Lake Chelan at the Narrows, as shown in profile.

The rocks of this uplifted mass, so far as they have been observed by Russell and the writer, consist of ancient schist, together with intruded granite, quartz-diorite, and similar igneous rocks. They afford no structure significantly related to the present upwarp, unless it be vertical jointing. The cleavage which they exhibit is probably of much more ancient date. Considered in detail, there are marked differences in structure and texture, which constitute elements of heterogeneity; but considered in mass the whole is remarkably homogeneous. The northern and western portions of the upwarp do, it is true, include areas of Mesozoic sedimentary rocks; but they may be considered as incidental, rather than characteristic, since they are quite subordinate in area and volume.

The evidence of the Methow upwarp being thus limited to physiographic phenomena, it is found first in the altitude of the Methow plain, whose position has already been described. By reference to the sections on Pl. XIX, it will be seen that it is essentially flat-topped and connected by gentle slopes with the position of the plain on three sides. Further evidence is found in the effects of corrasion, especially as exemplified in the canyons of Twisp and Chelan rivers, which are among the most profound and most sharply cut of the entire Cascade Range. That of the Twisp heads near the junction of the Methow uplift with the main Cascades, where the elevation of the flat surface is about 8,500 feet, and descends rapidly to its junction with the Methow at 1,600 feet. The greater part of this descent of 7,000 feet is made in the first 10 miles, and the canyon thence to its mouth is flat-bottomed. It is clearly the product of retrogressive activity of the stream working headwards against the slope of the upraised mass west of Methow River. The upper course of the stream is along the axis of the uplift, and there is a sharp bend by which the river turns, as it were, down the slope toward the Methow. It is possible that this change of direction is significant of an episode of capture in the history of the Twisp, which may formerly have flowed on in a continuous southeasterly course toward Libbey Creek; but no adequate study of the topographic forms has been made to determine that such was the fact. The development of the Chelan Canyon has already been described, and it has been shown that the relations between its several parts and to the old channels of Knapp and Navarre creeks are best explained as results of the opportunities for piracy which were provided by the growth of the Methow upwarp. The open valley of lower Lake Chelan is inconsistent in topographic phase with the great canyon above Twentyfive Mile Creek, and the inconsistency is regarded as evidence of the vigorous elevation from which the youth of the latter section follows. The mature aspect of topographic forms about the lower section of Lake Chelan, and the beheaded character of Knapp and Navarre coulees, are facts which show that the Lower Chelan region was relatively depressed as the Methow upwarp rose.

Chelan Butte upwarp.—South of Lake Chelan, and between it and the westward-trending course of Columbia River, is the striking eminence of Chelan Butte, having an altitude of 3,892 feet. The summit of granite dikes and schist is considered to be a monadnock, rising perhaps 400 feet above the Cascade plain. Thence westward extends a ridge having an elevation of 3,000 to 3,500 feet, which rises to the summit of Baldy Mountains, 6,432 feet, and continues northwestward in the Chelan Mountains, of which the culminating summit is Stormy Mountain, 7,219 feet. The heights of Baldy, Stormy, and other acute peaks which are largely maintained by outcrops of quartz diorite, are believed also to represent monadnocks above the Methow plain, the altitude of which is somewhat above 6,000 feet. South of this elevated ridge the Methow plain is recognized in the Waterville plateau at an elevation of 2,800 to 3,000 feet, that is at least 500 feet below its probable position on Chelan Butte, and is noted in Ribbon Mesa and in the hill rising to an altitude of 3,757 feet at 3,000 to 3,500 feet, or about 3,000 feet below its position about Stormy and Baldy mountains. This difference in altitude of the Methow plain is taken as representing the slope from the axis of an upwarp which corresponds with the trend of the Chelan Mountains from Stormy east by south to Chelan Butte, and which divides the basin of the Lower Chelan from that of the Waterville plateau. The peculiar physiographic relations of Knapp and Navarre coulees are interpreted as effects of this upwarp, across which the streams held their respective courses until they had cut deep canyons, but by which they were ultimately retarded until they were beheaded by the Little Chelan, a tributary of the Columbia north of the axis.

Waterville downwarp.—The Methow plain is very clearly preserved in the Waterville plateau and Ribbon Mesa, the latter lying west of Columbia River at a general altitude of 2,800 to 3,000 feet. The Methow plain is lowest, so far as observed, where it is represented in two small mesas southeast of Waterville, at an elevation of 2,800 feet, and from this least altitude it rises northward, westward, and southward as would the surface of a shallow spoon. This depression, which is recognized solely on the evidence of the deformed Methow plain, is an embayment between the Chelan Butte upwarp and that of Badger Mountain, and, like the basin of lower Lake Chelan, is a minor crenulation of the margin of the Cascade upwarp.

Badger Mountain uplift.—Badger Mountain, east of the Columbia, has already been described as a broad, low elevation of the Columbia Plateau. West of the river its axial continuation is the Entiat Mountains, which, extending northwestward, lie between the headwaters of Entiat and Wenatchee rivers. This line of mountains, although divided by the canyon of the Columbia, is a continuous zone of uplift, highest toward the northwest, and sinking southeastward into the level of the central plateau of Washington. Along this summit the Methow peneplain is recognized in Badger Mountain at an altitude slightly above 4,000 feet; in the eastern end of the Entiat Range at 4,800 to 5,000 feet; 10 miles farther northwest, about Cougar Mountain, at 6,000 feet; and near the headwaters of the Entiat at probably 6,500 feet. These are maximum elevations, from which the plain slopes away to the northeast down to the Waterville plateau and Ribbon Mesa, already described, and to the southwest into the valley of the Wenatchee. Adjacent to the Wenatchee Canyon its probable altitude is not far from 4,000 feet. On the evidence of the relative altitudes of the old plain, the Badger-Entiat axis is recognized as a zone of local uplift. This inference is sustained by an examination of the canyon of the Columbia, and its relation to the Columbia Valley of the Entiat cycle, as appears from a comparison of the depth of the canyon abreast of Badger Mountain with that below Chelan Butte, and the relative altitudes of the old valley floor in the corresponding positions. The fall of the Columbia at the present time from Chelan Butte to Wenatchee, a distance of 25 miles, is about 15 feet, and may therefore be left out of consideration, the river being taken as a level datum. The depth of the canyon below the older valley at Chelan Butte is 800 feet, and abreast of Badger Mountain is 2,000 feet; that is to say, the old valley floor is 1,200 feet higher above the practically level river bed 25 miles farther downstream. As the river can not be supposed to have flowed up this slope, it is evident that the valley floor has been raised 1,200 feet more at the Badger Mountain axis than it has south of Chelan Butte. This relation demonstrates the ability of the antecedent Columbia River to maintain its course across the rising uplift.

Wenatchee downwarp and upwarp.—The Wenatchee Valley, like the Methow, is floored in part by sedimentary rocks which are more easily eroded than the schist and granite and basalt of adjacent districts; and as it has been deeply eroded by both ice and water, its physiographic features are complex. It is inferred that it corresponds to a downwarp having the form defined by the contours, and that it is limited on the southwest by the Wenatchee upwarp. The broad, evenly sloping surface of the latter is thought to represent very closely the Methow plain.

EPISODES OF DEFORMATION.

PRE-TERTIARY DEFORMATION.

The latest effects of deformation, those which have been described and which are of late Tertiary and post-Tertiary date, are but the most recent of a number of movements whose history within the Cascade province no doubt goes back to the earliest geologic events that can there be recognized. It would not fall within the scope of this article to discuss pre-Tertiary movements, even were adequate data available, but it is desirable to point out that each of the major downwarps of post-Tertiary time corresponds in position with a synclinorium in which pre-Tertiary sediments were deposited. Cretaceous strata occur in the Methow downwarp, and Eocene deposits are extensively developed in the Wenatchee and Yakima downwarps, whereas on the intervening upwarps the rocks are very much older. With regard to the Cretaceous, we can not say that the limits of geographic distribution of the sediments correspond with the depression which developed later. Indeed, the Cretaceous rocks extend across the northern part of the Cascade upwarp, where they occur upturned to dips of 90 degrees. The basins of Eocene strata, on the other hand, were of local character, and apparently do correspond somewhat closely to the respective downwarps in which they are found; but this is not true, as pointed out by G. O. Smith, in regard to the Miocene of the Yakima Valley. Rocks of Miocene, Eocene, Cretaceous, and earlier ages had suffered compressive stress and been folded during more than one epoch of deformation before the beginning of that late Tertiary topographic cycle during which the Methow peneplain developed.

From these facts it is apparent that the post-Tertiary deformation was not a peculiar effect initiated in a region previously little disturbed, but was merely the successor of other effects to which it may be genetically related, in so far as a common cause may have acted in this province from an early geologic date.

This is an expression of a fact which is of general occurrence so far as the writer's observation goes, namely, that a region of orogenic movement has commonly been the scene of repeated mountain growths widely separated in time. The reverse (that there are extensive provinces in which mountainous elevations have not developed) is also true, and the facts thus point to persistence, intermittence, and localization of the causes of orogeny.

TERTIARY AND POST-TERTIARY DEFORMATION.

All that follows relates to deformation which is later in time of occurrence than the planation of the Methow peneplain. The effects as a whole might be summed up in the phrase the growth of the Cascade Range. The general effect is the uplift of the mass from which the Cascade Mountains are carved, and the details have been described in preceding paragraphs.

Through a study of the physiography, and particularly of the Columbia River Valley above Wenatchee, two episodes of deformation have been distinguished, the first being that which occasioned the Entiat cycle of physiographic development, the second that which gave rise to the Twisp cycle. Referring to the table of physiographic development, it will be seen that these may both be considered pre-Glacial—that is, pre-Pleistocene—if the glacial conditions of the Cascade Range be found to have been restricted to a single episode; or the Entiat and Twisp cycles may both fall within the Pleistocene if two or more glacial episodes should be recognized. The writer inclines to the belief that the latter interpretation is correct, the reasons being that the condition of planation reached during the Methow cycle was probably such as to require most of Pliocene time for its development, and, further, that there is distinct evidence in the drift deposits of Puget Sound of two well-separated glacial invasions. Thus it seems probable that both episodes of growth of the Cascade Range fall within the Pleistocene division of the Quaternary.

It has been pointed out by G. O. Smith that effects of upwarping and downwarping, which in the Yakima Valley may be regarded as effects of Twisp date, correspond to anticlines and synclines that developed before the Methow plain reached its last phase. Smith does not in his area recognize the Entiat stage, and no comparison of effects of that stage with others is made by him. In the region north of the Wenatchee, however, it seems probable that upwarps and downwarps which were moderately developed during the Entiat cycle were greatly accentuated during the Twisp cycle, and that there was practical coincidence of the axes of elevation and depression during the two different episodes. Thus the Columbia Valley across the Entiat-Badger Mountain upwarp is deeper for each of the two cycles than the corresponding valley south of Chelan Butte, and it follows from this fact that the axis of upwarping was well marked in the earlier as well as in the later stage of deformation. Many of the facts of physiographic development which have already been adequately discussed point in the same direction.

CAUSES OF DEFORMATION.

DIRECTION OF STRESS.

Granting that theoretically stress may be exerted in the earth's crust from any direction, it is convenient to discuss effects of stress as due to vertical or horizontal components, which are thus taken as being those forces that have given rise to deformation; and in what follows there is a tacit assumption that we have to deal in this particular case with effects either of vertical stress or of horizontal stress, one or the other and not both.

Vertical stresses appear at first sight more probably to have been the effective causes of vertical uplift than horizontal stresses, and the imagination appeals to the intrusion of deep-seated batholiths of granite beneath the elevated mass of the Cascade Range. In doing so it can point to pre-Eocene and Miocene intrusions of granite within the area; it may emphasize the fact that the principal monadnocks above the Methow plain are of granite Mount Stuart being the most striking and important example, and from the occurrence of granite within the areas of upwarps it may argue a coincidence of intrusion with uplift. The last-named point is, however, in a measure invalidated by the fact that the occurrence of granite beneath the later sediments which lie in the downwarps can neither be affirmed nor denied. Against the hypothesis that the deformation of the Cascade Range is due to vertical stress, and possibly to batholithic intrusion, are the generally observed facts that the rocks everywhere exhibit phenomena of jointing and flexure due to compression and that folds in the bedded basalts of the Yakima Valley are even overturned.

Turning to consider the effects of tangential or horizontal compressive stress, it is desirable to distinguish two classes of effects, one of which may be known as competent structure, the other as incompetent structure, involving shear or flow. Competent structure is exhibited in an elevation of stratified rocks such as is commonly described by the term anticline. It is developed under conditions that direct the effective component of the stress in the direction of bedding. At any point of change of dip the stress is resolved into two components, one of which continues in the farther direction of bedding, and the other acts radially to elevate the stratum with the load resting upon it. The requirements of development of the structure are those of an arch capable of supporting the superincumbent load, and the proportions of the structure are limited accordingly. From these considerations it follows that anticlines raised under the law of competent structure are relatively narrow.[a]

The horizontal extent of the Cascade uplift is so great as compared with its height that if regarded as an arched structure it is exceedingly flat. Its width varies from forty to sixty times its height; and it is clear that no section of a body of rocks thus extending over two or three scores of miles can be looked upon as self-sustaining. It follows that the elevation of the range as a competent structure can not be considered.

The development of incompetent structure by compression results in shortening the mass in one direction, or in two directions; with corresponding elongation of the other dimensions, or of the third dimension. The change of volume, if there be any, is assumed to be negligible; that is, in considering this type of deformation the volume is taken to be constant. The strain may be that which is described by Becker as a simple shear,[a] or that which Van Hise denotes by the term pure shortening.[b] The distinction lies in the internal structures developed within the mass, the change of form as a whole being the same in either case.

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[a] Willis, Mechanics of Appalachian structure: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 2; Van Hise, Principles of pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1.

It has been shown by Becker, through mathematical analysis,[c] that dividing planes develop through simple shear in elastic brittle masses at angles approaching 45 degrees to the direction of stress, and this theoretical conclusion has been abundantly substantiated through experiment. On the other hand, Van Hise and Hoskins have shown that in case a rock mass has been made to flow in a direction of least resistance, cleavage planes are developed in a normal attitude to the direction of stress. The structural change is apparently one involving minute movements upon many parallel planes, accompanied by the rotation of already existing mineral particles and the development of new minerals whose longest axes are parallel to the direction of flow. This structure develops only in the zone of flow and gives rise to "flow cleavage." Shear, as described by Becker, may occur in any rigid mass, in the zone of flow or in that of fracture; in the zone of flow it does not correspond with flow cleavage; in the zone of fracture it may give rise to independent "fracture cleavage" or jointing.

The structural phenomena of the Cascade Range are illustrated in the two views of Pl. XX, which were both taken within a mile of Cascade Pass at the head of the Stehekin. In *A* the cliff rising above the lake exhibits near the center of the view a number of inclined joint planes, which are sufficiently well marked to have determined the courses of the rivulets descending from the slope above. No exact observations of the dips of these planes are available, but they appear to lie at such an angle to the horizontal as possibly to come within the limits assignable to the attitude of shearing planes or fracture planes. They may be hypothetically regarded as effects of shear developed in the zone of fracture through a horizontal compressive stress. In Pl. XX, *B*, a nearly vertical cleavage structure is clearly exhibited in the details of topographic forms. It is that structure which if dominant in the heart of the Cascade uplift, and so far as macroscopic examination shows it has the characteristics assigned by Van Hise to cleavage developed in the deep zone of flow. The inference which may, with some assurance, be drawn from its widespread occurrence is that the mass of the Cascades was deformed while that portion now exposed in the highest peaks was still very deeply buried.[d]

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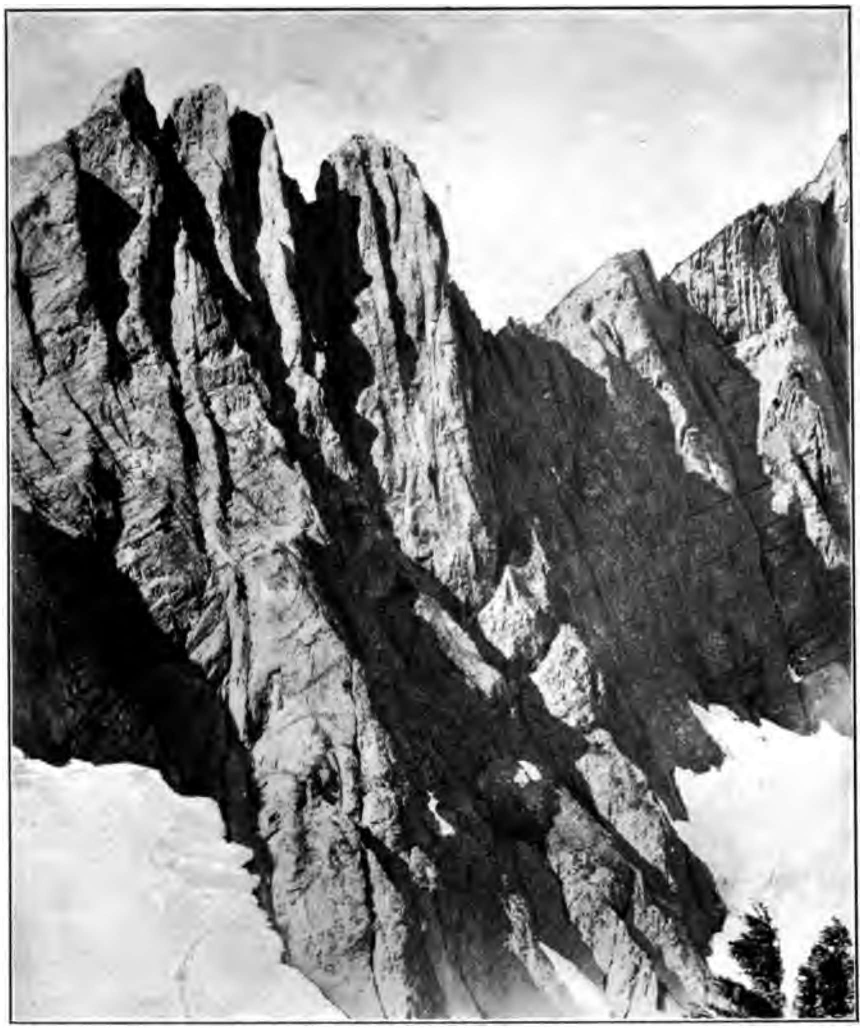
[a] Finite homogeneous strain, flow, and rupture of rocks: Bull. Geol. Soc. America, vol. 4, p. 22.

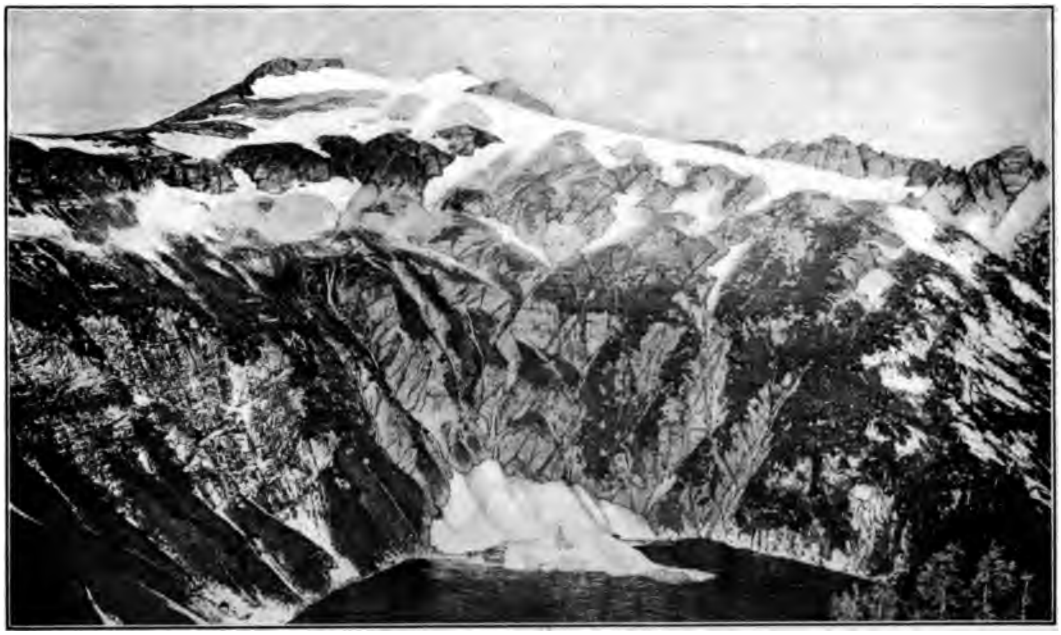
[b] Principles of North American pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, p. 636.

[c] Ibid., p. 30 et seq.

[d] For related observations see Spurr, J. E., Ore deposits of Monte Cristo, Washington: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 801-802.



A SOUTHERN SLOPE OF BOSTON MOUNTAIN, SHOWING INCLINED JOINT PLANES.



B. PINNACLES SOUTHWEST OF CASCADE PASS, SHOWING VERTICAL JOINTING.

Flow cleavage and fracture cleavage structure have a common origin in compressive stress. The observed structures in the Cascade Range occur generally throughout the mountains, and can not be separated according to locality. They may perhaps be distinguished by date. If it should be found that the fracture cleavage developed in the zone of flow cleavage, the two may be assigned to a common episode of deformation, the date of which must be set so far back that the cleaved rocks were exposed through erosion before the development of the Methow plain; that is to say, to a pre-Pliocene date. On the other hand, it may be that the fracture cleavage or jointing was predominantly developed in the zone of fracture, and must be assigned to a date at which the rocks that it now traverses were nearer the surface than they had been when the flow cleavages were formed. In this case the relation of the inclined jointing to the pre-Pliocene cleavage may be such that the shearing can be attributed to that compressive stress which is thought to have caused the elevation of the Cascade mass as it is now observed. This is the conclusion reached by Spurr.[a]

DIMENSIONS OF THE CASCADE BLOCK.

The speculations of the preceding paragraph in regard to the depth at which the structures may have developed naturally lead to consideration of a problem which may be stated thus: What may have been the depth of the prism which in consequence of compression horizontally was so elongated vertically as to produce the Cascade uplift. There are many qualifying factors, the data for which are incomplete or wanting; numerical results, therefore, can at best indicate only an order of magnitude, yet nevertheless there may be profit in stating the conditions of solution.

Stripped to its purely mathematical form the problem is: Given a prism, supported in isostatic equilibrium and subjected to strains in consequence of which its width, length, and height are changed, but without change of volume; and given the width before and after strain, the ratio of lengths before and after strain, and the amount of vertical elongation, to calculate the original height.

Through the courtesy of Mr. George F. Becker the following mathematical analysis is given:

UPLIFT BY HORIZONTAL COMPRESSION.

The original dimensions of a block are x, y, z, where y is vertical.

As a result of strain the dimensions become x′, y′, z′, and the volume remains constant.

Let $x' = \alpha x$ and $z' = \beta z$, then $y' = \frac{y}{\alpha \beta}$.

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[a] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, p. 802.

In a given case suppose that we know

$$\frac{x'}{x}=\alpha, \text{ and } y'-y=b;$$

Then,

$$y'-y=y'-\alpha\beta y'=y'\,(1-\alpha\beta);$$

So that

$$y'=\frac{b}{1-\alpha\beta} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

Here y' may be estimated on various hypotheses:

A. If $\beta=1$, or if there is no strain in the direction of z, (1) gives

$$y'=\frac{b}{1-\alpha} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

B. If the strain is the same in the directions x and z, (1) gives

$$y'=\frac{b}{1-\alpha^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

C. If the strain is the same in the directions y and z,

$$\frac{1}{\alpha\beta}=\beta, \text{ so that } \beta=\frac{1}{\sqrt{\alpha}} \text{ and (1) becomes}$$

$$y'=\frac{b}{1-\sqrt{\alpha}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

To apply this general formula to the special case of the Cascade uplift we may approximate to x, the original width, on the warped surface of the peneplain; may measure x′, the present width, as the distance from the western to the eastern base of the uplift at sea level; and may determine the amount of vertical elongation as the mean elevation of the warped surface above sea level.

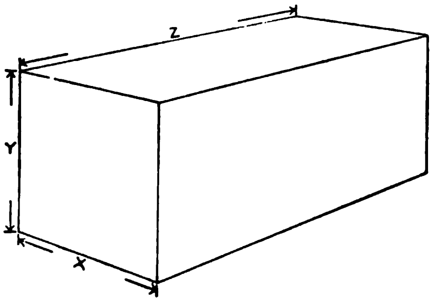

FIG. 2.—Diagram of a block.

The complete form of the upwarped surface not having been worked out, it appears best to express, between rather wide limits, the relations of the width x before strain to the present width x′. According to an estimate based on measurements of the warped surface from Columbia River over the Methow Mountains, the width on the warped surface must exceed that on the sea-level line by more than one-tenth of a mile in a hundred miles, and this may be taken as the least possible ratio of x to x′. Whereas, on the other hand, this ratio probably does not exceed 2 miles in 100, since the width on the warped surface is an arc A C B and is considerably shorter than the distance A D E B, which, if the mean height be 1½ miles, is 3 miles. The altitude of the Cascade upwarp being about 8,500 feet over a large area, a mean height of 1½ miles is probably a reasonable estimate. In latitude

INDEX.

Page.
Agnes Creek, topography of region near 83
Andesite, occurrence of 18
Arid areas, Entiat features in 79
Badger Mountain, a residual of the Methow plain 72
  altitude of 49
  character of 90
  location and general features of 51, 52–53, 79–80
Badger Mountain uplift, description of 90
Baker, Mount, Cascade plateau near 31
Baldy Mountain, height of 62, 89
  rocks and topography of 65
Basalt, occurrence and character of 11, 12, 15–17, 50, 64, 84
Becker, G. F., cited on deformation 94
  mathematical analysis applicable to Cascade uplift furnished by 95–96
Boston Mountain, view of, plate showing 94
Calkins, Frank C., aid rendered by 10
Campbell, M. R., references to 35, 47
Cascade lowland, deformation of 39
  extent and development of 26–28
  period of development of 28
  remnants of, identification of 24–26, 27–28
Cascade Mountains, canyons in, features of 81
  drainage of 9
  elevation of, lack of uniformity in, cause of 29
  physiographic problems in, stream evidence bearing upon 32
Cascade Pass, views near, plates showing 54, 94
Cascade peneplain, hypothesis of 12
Cascade plateau, age of 47
  dissection of, variations in 30–32
  history of 12
  remnants of 48
  uplift forming, character of 29–30
Cascade Range, age of 10
  deformation of 85–91
  geologic formations of 11
  glaciation in 19
  origin of 10–12
  physiographic development of, table showing 70
  structure of 10–11
  summit level of, uniformity of 75
  summits of, views of 74–75
  system of antecedent drainage in, identification of. 34
  uplift of central portion, character of 34–35
  views of 50, 54, 66, 94
  views from, features of 74–75
Cascade uplift, height of 85
  horizontal extent of 85–86, 93
  marginal flexures of 86–91
  mathematical analysis of 96
  strained mass of, estimated depths of 97

Page.
Chelan Basin, drainage of 61
  glaciation in 59, 60
  rocks of 60
Chelan Brook, location and drainage area of 61
Chelan Butte, age of 77
  height of 77, 89
  physiography of 50, 77
  view of, plate showing 60
  views from, plates showing 64, 66
Chelan Butte upwarp, description of 89–90
Chelan Falls, glaciation near 80
Chelan, Lake, basin of, depth of, theories to explain .. 82–83
  basin of, features of 81–83
  description and geologic history of 58–63
  divide between Lake Creek and 62–63
  drift dam at 58
  elevation and depth of 81–82
  geologic features of region near 60
  glacial ice at, thickness of 82
  glaciation near 59, 60
  physiographic features of Columbia gorge correlated with features of 60
  Narrows of, location of 59–60
  Narrows of, plate showing 62
  rocks near 60
  views of, plates showing 62, 66
Chelan Lake Basin, lower part of, physiographic history of 58–61
  upper part of, physiographic history of 61-63
Chelan Lake-Wenatchee River district, drainage of .. 53
Chelan Mountains, physiography of 65–66
Chelan quadrangle, northern half of, physiographic map showing 74
  southern half of, physiographic map showing 72
Chelan Range, character and position of 59
Chelan River, historical events of 53
Chelan stage, age of 70
  records of, character of 81
  characteristics of 69
Chelan-Stehekin drainage system, glaciers of 82–83
Chelan-Stehekin River, source and course of 58, 63
Cleman Mountain, landslide topography of 23
Clealum Ridge, structural relations of 20
  topographic characters of 20
Clealum River, course and character of 38
Coberly Creek, topography at head of 52
Columbia River, elevation of 49
  glaciation along 80–81
  gorge of, features of 49–51
  gorge of, features of, correlated with those of Lake Chelan 60
  gorge of, glaciation in 20

Page.

- Columbia River, peaks near 49–50
  - plateau marked by 51
  - tributaries of, topographic and other features of 53–63
- Columbia River Canyon, history of 80–81
  - physiography of 49–50
  - walls of, recession of 80–81
- Columbia River lava, description and history of 11–13
- Columbia Valley, twofold character of 76
  - view of, plate showing 64
- Cooper Mountain, character of 73
- Davis, W. M., references to 47, 68
- Dawson, G. M., reference to 74
- Deformation, causes of 92–97
  - diagrams illustrating 96, 97
  - discussion of 83–97
  - episodes of 91–92
  - fundamental propositions concerning 84
  - post-Tertiary, evidence of 92
  - pre-Tertiary, evidence of 91
  - Tertiary, evidence of 92
- Easton schist, age, character, and occurrence of 14
- Ellensburg formation, age, character, and thickness of. 17–18
- Ellensburg quadrangle, area, location, and features of. 9
  - basalt interbedded with sandstone in 17
  - geologic map of portion of 18
  - physiographic sketch map of portion of 26
  - structural features of 21
- Ellensburg sandstone and Yakima basalt, contact of, figure showing 27
- Entiat Mountains, altitudes attained by 49
  - physiography of 64
- Entiat relief, degree of 77–78
- Entiat River, description and history of 55–56
  - diversion of 64
  - features of history of 53
  - old channel of 56
- Entiat slope, line of demarcation between Twisp slope and 76
- Entiat stage, age of 69, 70
  - features of, in arid areas 79–80
  - first recognition of 76
  - glaciated remnants of 78
  - physiographic relations of 75–76
  - position and form of 68, 75
  - residuals of, distribution and character of 76–80
  - topography of, maturity of 78–79
- Entiat Valley, physiography of 55–56
- Eocene rocks, folds in 20
  - occurrence and character of 15–16
  - thickness of 39
- Farmer, R. A., reference to work of 49
- Fourmile Ridge, Chelan Mountains, age of formation of 66
  - height of 73
  - physiography of 65–66
  - rocks of 65
- Geologic history, summary of 21–22
- Geologic structure, features of 19–21
- Gilbert, G. K., references to 84, 35, 47
- Glacial ice, thickness of, at Lake Chelan 82
  - thickness of, at Safety Harbor Creek 82
- Glaciers of Chelan-Stehekin system, former extent of. 82–83
- Gold Creek, view from head of, plate showing 50
- Granite, occurrence of 60, 65
- Granite-porphyry, occurrence of 60
- Granodiorite, occurrence and character of 15
- Griswold, W. T., reference to work of 49
- Hawkins formation, age and character of 14

Page.

- Hayes, C. W., reference to 47
- Hornblende-gneiss, occurrence of 65
- Hoskins, L. M., cited on rock flowage 94
- Hypersthene-andesite, occurrence of 18
- Icicle River, character of 82
- Igneous rocks, occurrence and character of 14–15
- Kittitas Valley, features of 24–25
- Knapp Coulee, features of 56–57, 61
  - history of 57
- Knapp Creek, diversion of, by deformation 61
  - drainage area of 61
- Knowlton, F. H., determinations of fossil plants by 17, 47
- Lake Creek, divide between Lake Chelan and, height of 62–63
- Landslides, occurrence of 23, 51
- Lava, basaltic, occurrence of 50
- Lavas, eruptions of 11, 18
- Manastash formation, occurrence and character of 16
- Mascall formation, correlation of 17–18
- Methow downwarp, description of 86–87
- Methow Mountains, area of 67
  - character and position of 59
  - features of 66–67, 73
  - heights of 67
  - location of 66
  - profiles of, west of Navarre Peaks 75
  - rocks of 60
  - topography of 73
- Methow peneplain, altitude of 87, 90
- Methow plain, altitude of 87, 89–90
  - probable origin of 70–71
  - residuals of, distribution and character of 72–75
  - rocks of 71
  - topography of 71–72
- Methow quadrangle, southern half of, physiographic map showing 76
- Methow River, course, elevation, and grade of 87
  - glacial deposits along 87
- Methow stage, age of 69, 70
  - characteristic feature of 70
  - conditions of development of 70–75
  - downwarp during 86–87
  - topographic type of 68
  - upwarp during 88–89
- Methow Valley, glacial deposits in 87
  - trend of 86–87
- Miocene rocks, occurrence and character of 16–19
- Moses Creek, topography at head of 51–52
- Mount. (*See* next word of entry.)
- Mount Stuart quadrangle, area, location, and features of 9
  - dissection in 31
  - geologic map of portion of 14
  - geologic structure in 19–20
- Naches River, character and history of 33
  - Ellensburg formation along 18
- Naches Valley, lava streams along 18
- Navarre Coulee, features of 56, 57, 61
  - history of 57
  - view of, plate showing 56
- Navarre Creek, diversion of, by deformation 61
- Navarre Peaks, age of 73–74
  - height of 67
  - relations and origin of 67
  - view of, plate showing 66
- Navarre stream, tributaries of 61
- Oval Peak, height of 75
- Peridotite, occurrence of 14–15

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
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A
RECONNAISSANCE IN NORTHERN ALASKA

ACROSS THE ROCKY MOUNTAINS, ALONG KOYUKUK, JOHN, ANAKTUVUK, AND COLVILLE RIVERS, AND THE ARCTIC COAST TO CAPE LISBURNE, IN 1901

BY

FRANK CHARLES SCHRADER

WITH NOTES BY

W. J. PETERS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1904

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Stanford University, Calif.

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CONTENTS.

Page.

Letter of transmittal 9

Introduction 11

Methods of work 14

- Dog sledding 14
- Camping 15
- Chronologic summary of operations 15
- Methods of scientific work 17

Itinerary and topographic methods, by W. J. Peters 18

- Plan of operations 18
- White Horse to Bergman 19
- Reconnaissance up Alatna River 20
- Reconnaissance up John River 20
- Canoe trip from Bettles to Point Barrow 21
- Methods of topographic work 24

Previous explorations 25

- Historical sketch 25
- Chronologic list of works 31

Population and conditions 33

- On the Koyukuk 33
  - Natives 33
  - Whites 34
  - Transportation and means of travel 34
  - The placers 35
- On the Arctic coast 35
  - Natives 35
  - Whites 36
  - Transportation and means of travel 37

Table of distances 37

Geography 38

- Location and general features 38
- Mountain province 39
  - Endicott Mountains 40
    - General features 40
    - Ancient plateau feature of Endicott Mountains 42
    - Drainage 43
- Koyukuk province 44
  - General features 44
  - Drainage 45

Geography—Continued.

Page.
- Arctic slope province 45
  - Anaktuvuk Plateau 45
  - Arctic Coastal Plain 46
  - Drainage 46
    - Colville River 46
    - Anaktuvuk River 48
  - Coast line 48
      - From Colville River to Point Barrow 48
      - From Point Barrow to Cape Lisburne and beyond 49

Geology 50
- Geological map and sections 50
- Outline of geologic history 52
- Sedimentary rock formations 55
  - Paleozoic rocks 55
    - Structure 55
    - Skajit formation (Upper Silurian) 56
      - Character and occurrence 56
      - Structure 56
      - Age 57
      - Correlation 58
    - Totsen series (Silurian) 58
      - Character and occurrence 58
      - Structure 59
      - Age 59
      - Correlation 59
    - Stuver series (pre-Devonian) 60
      - Character and occurrence 60
      - Structure 61
      - Age 62
      - Correlation 62
    - Lisburne formation (Devonian) 62
      - Character and occurrence 62
      - Structure 64
      - Age 64
      - Correlation 65
      - Distribution 67
    - Fickett series 67
      - Character and occurrence 67
      - Structure 69
      - Age 70
      - Correlation 71
  - Mesozoic rocks 72
    - Corwin series (Jura-Cretaceous) 72
      - Character and occurrence 72
      - Structure 73

Geology—Continued. Page.

Sedimentary rock formations—Continued.

Mesozoic rocks—Continued.

Corwin series (Jura-Cretaceous)—Continued.

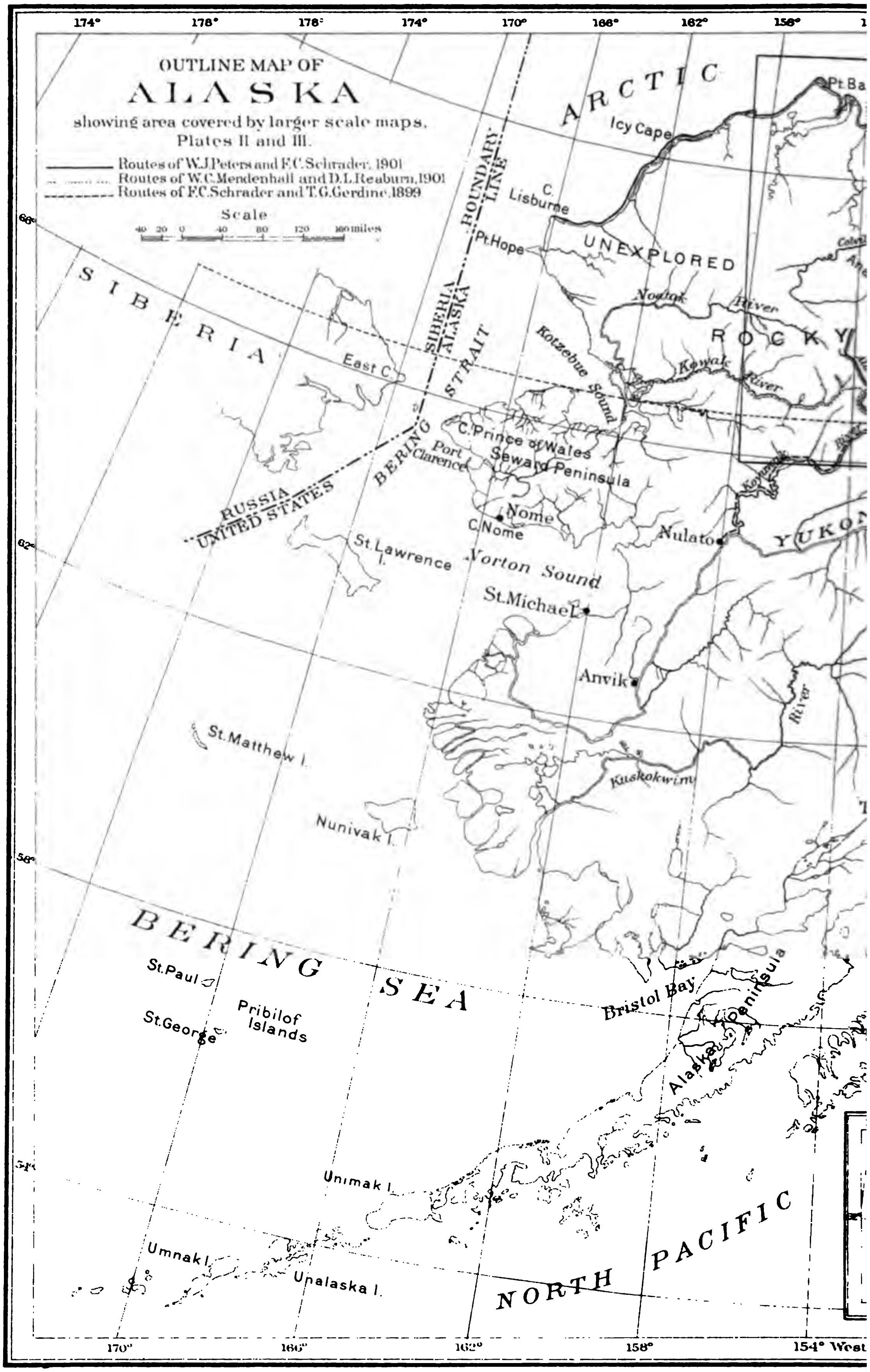
Age 74
Correlation 74
Anaktuvuk series (Lower Cretaceous) 74
Character and occurrence 74
Structure 75
Age 76
Correlation 76
Koyukuk series (Lower Cretaceous) 77
Character and occurrence 77
Structure 77
Age 77
Correlation 77
Bergman series (Cretaceous?) 77
Character and occurrence 77
Structure 78
Age 78
Nanushuk series (Upper Cretaceous) 79
Character and occurrence 79
Structure 80
Age 80
Correlation 80
Tertiary rocks 81
Colville series (Oligocene and Pliocene) 81
Character and occurrence 81
Structure 82
Lower Colville (Oligocene) 82
Upper Colville (Pliocene) 83
Pleistocene deposits 84
Glacial deposits and glaciation 84
Ground-ice formation and Kowak clay 91
Gubik sand 93
Recent mud, muck, ground ice, dune sand, silts, and gravels 94
Inland region 94
Coastal region 95
From Colville River to Point Barrow 95
From Point Barrow to Cape Lisburne 96
Recent fossils from the Arctic coast 96
Table of provisional correlations 97
Mineral resources 98
General statement 98
Gold 98
Copper 104

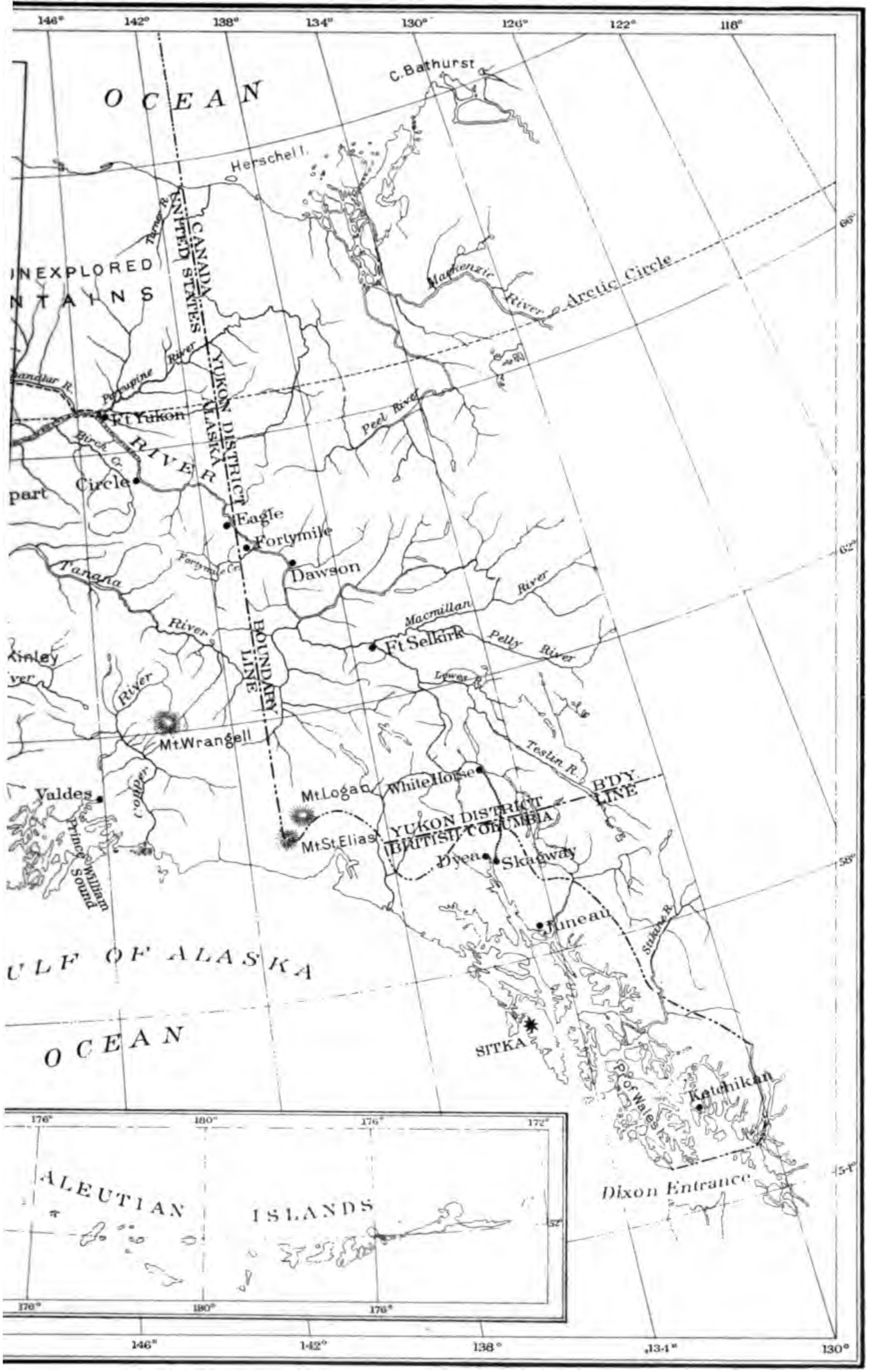
Mineral resources—Continued. Page.
- Lead 105
- Antimony 105
- Zones of metalliferous mineralization 105
  - In the Totsen series 105
  - In the Fickett series 106
- Coal 106
  - General statement 106
  - Koyukuk region 107
    - Koyukuk River 107
    - John River 107
  - Arctic slope 107
    - Anaktuvuk River 107
    - Colville River 107
  - Northwest coast 109
    - Wainwright Inlet 110
    - Cape Beaufort 110
    - Thetis and Corwin mines 111
    - Area south of Cape Lisburne 113
  - Analyses of coal 114

Climatic conditions 114
- Meteorologic record for 1899 114
- Meteorologic record for 1901, by W. J. Peters 122
- Meteorologic record for 1885–86, by Lieut. G. M. Stoney 123
- Temperatures in 1901 125

List of arctic plants collected 130

Index 135


OUTLINE MAP OF
ALASKA
showing area covered by larger scale maps.
Plates II and III.
Routes of W.J.Peters and F.C.Schrader, 1901
Routes of W.C.Mendenhall and D.L.Reaburn, 1901
Routes of F.C.Schrader and T.G.Gerdine, 1899
Scale
40 20 0 40 80 120 160 miles
174° 178° 178° 174° 170° 166° 162° 158°
170° 166° 162° 158° 154° West
66° 62° 58° 54°
ARCTIC
Pt.Ba
Icy Cape
C. Lisburne
Pt.Hope
UNEXPLORED
Noatak River
ROCKY
Kotzebue Sound
Kowak River
SIBERIA
East C.
BOUNDARY LINE
SIBERIA ALASKA
STRAIT
BERING
RUSSIA
UNITED STATES
C.Prince of Wales
Port Clarence
Seward Peninsula
Nome
C.Nome
Nulato
YUKON
St.Lawrence I.
Norton Sound
St.Michael
Anvik
River
St.Matthew I.
Kuskokwim
Nunivak I.
BERING SEA
St.Paul
St.George
Pribilof Islands
Bristol Bay
Alaska Peninsula
Unimak I.
Umnak I.
Unalaska I.
NORTH PACIFIC



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A RECONNAISSANCE IN NORTHERN ALASKA IN 1901.

By F. C. SCHRADER.

INTRODUCTION.

Since 1898 the United States Geological Survey has been carrying on systematic topographic and geologic surveys in Alaska under an appropriation made for the investigation of the mineral resources of the Territory. This work has included not only areal surveys of regions already being developed by the miner and prospector, but also explorations and investigations of regions that are little known or entirely unexplored. As a result of these explorations a network of reconnaissance traverses has been extended over a large part of Alaska, where route surveys of this character must necessarily precede more detailed topographic and geologic mapping. They serve to outline the main geographic features of the country and afford the pioneer or prospector a guide for his journeys as well as help him to select his field of operations. The present report and maps are the results of such an investigation.

Previous to 1901 but two journeys[a] which yielded any geographic results had been made across northern Alaska by white men. The first of these was made by Lieutenant Howard, U. S. Navy, in 1886, and extended from Kowak River to Point Barrow, while the second, made by J. H. Turner, in 1890, followed the one hundred and forty-first meridian from the Porcupine. The conditions under which these journeys were carried on precluded instrumental work. The present survey must therefore be considered the first made with precise instruments from the Yukon to the north coast of Alaska. In connection with the traverses made of Chandlar and Koyukuk rivers by Mr. T. G. Gerdine, and of Dall, Alatna, and Kowak rivers by Mr. D. L. Reaburn, both of the Geological Survey, it outlines some of the most important of the physical features and drainage channels of northern Alaska.

The exploration on which the following report is based was made by the writer during the season of 1901, while attached as geologist to a party in charge of W. J. Peters, topographer. The other members of the party were Gaston Philip, topographic assistant; Thomas M. Hunt, George H. Hartman, Charles H. Stuver, Ben

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[a] For references and details see pp. 29 and 33 of this report.

Bennett, and Joe Edge, camp hands, all of whom rendered untiring and efficient service and manifested genuine interest in the expedition. Sections prepared by Mr. Peters are credited to him in the proper places.

As early as 1896 the Survey considered projects for reaching this unexplored field in northern Alaska, but owing to the remoteness of the region and the difficulties of transportation, no plans could be devised which did not involve the wintering of a party in this arctic country at great cost and much loss of valuable time. The first plans submitted were by Mr. J. E. Spurr, who proposed a traverse from the lower Koyukuk to Point Barrow, essentially along the route followed by Howard. The probable existence of a passable route 200 miles east of the above, between the upper Koyukuk and the Arctic slope, was not learned until 1899. The transportation difficulty, however, became less formidable when the discovery of gold on the Koyukuk, in the widespread search which attended the Klondike excitement of 1897 and 1898, led to the location of a trading post at Bergman, on Koyukuk River, near the Arctic Circle, nearly 500 miles above its mouth, and subsequently to annual visits to this post by the steamboats of a reliable company.

In the light of this later information, gained by a visit to the upper Koyukuk in 1899, the plans of the present expedition were formulated by the writer and submitted to the Director of the Survey, who approved them, and preparations were accordingly begun in the spring of 1900. The writer being otherwise engaged, the task of purchasing and assembling at San Francisco the necessary outfit, including four months' provisions for eight men, fell to Mr. Alfred H. Brooks, who was aided by Mr. R. B. Marshall.

The outfit, including canoes and supplies, was shipped from San Francisco through the Alaska Commercial Company early in the spring of 1900 and stored at the Bergman post until called for by the Survey party in 1901. From this base it was planned to carry the work northward across the Rocky Mountains of northern Alaska to the Arctic coast, and to conduct a parallel return traverse, from some other point on the coast than that at which it was reached, southward into the Koyukuk Basin, if conditions should permit. In case the return trip to the Koyukuk should be found impracticable the party was to proceed northwestward along the coast and seek relief at Point Barrow, where it was hoped it might be picked up by a returning revenue cutter or arctic whaler. In the event, however, that no such vessel appeared (as proved to be the case), it was proposed to at once continue southwestward along the coast in native skin boats or by dog sleds, as conditions might permit, until some chance vessel along the coast or some mining camp in the Nome region should be reached.

As this northern region was practically unsurveyed and much of it was entirely unexplored, it was planned to make an instrumental survey along the route of travel, which was to traverse the Rocky Mountains stretching across northern appreciated to pass without notice. Thanks are also due to Mr. Charles Brauer and others for hospitality and courtesies received at Cape Smyth, and to Captain Ericson for transportation on the steamship *Arctic* from the Corwin coal mines, near Cape Lisburne, to Nome.

The determinations of the fossils collected on the trip and referred to in this report were made by Drs. Lester F. Ward, W. H. Dall, T. W. Stanton, George H. Girty, Mr. Charles Schuchert, and Prof. William M. Fontaine, each dealing with the fossils from the horizons of which he has special knowledge. The coal analyses and mineral tests were made by Messrs. George Steiger and H. N. Stokes in the chemical laboratory of the Survey, and the assays for gold and silver by E. E. Burlingame & Co., of Denver, Colo. Fig. 1 (p. 40) and other information bearing on the Cape Lisburne region have been generously contributed by Mr. A. G. Maddren.

METHODS OF WORK.

Dog sledding.—As the success of the work required the surveyors to reach the field before the break-up of winter, and Point Barrow by September 1, the party set out from Skagway early in February, and, after proceeding over the Coast Range by the White Pass Railway, traveled by dog sled from White Horse 1,200 miles down the Yukon to Bergman, which was reached April 10. Traveling by this means is known, in the language of the country, as "mushing," and the traveler is called a "musher." The "musher" does not ride on the sled, which is used only for carrying the absolutely necessary supplies and luggage, but follows the sled afoot and urges the dogs forward, or runs ahead on snowshoes to break a trail where none exists, or where, as frequently happens, it has been drifted over. To keep trail breaking and friction in travel at a minimum the dogs are all hitched tandem, from five to nine in a team. The Survey party used four teams, or about forty dogs in all. Their feed, which is given once a day, usually at night, consists of some cereal, rice, meal, or flour, cooked with meat, fish, or grease. Rice and bacon, flavored with a little dried salmon, is best. It is affirmed by experienced and reliable prospectors throughout Alaska that on arduous prospecting trips, where a man is dependent for sustenance on the food supply packed on his own back, he, too, can go farther and accomplish a greater amount of hard work on rice and bacon than on any other ration.

At the present day two classes of dogs are used for sledding in Alaska—the "inside" or native, consisting of Siwash and Malemut, and the "outside," consisting of various breeds of imported dogs, principally from the United States. The outside dog excels in intelligence and is usually desirable for a leader, but the native dog is best for all-round service and for long, hard trips, as he requires less food and care, and having a dense pelt, much like that of the wolf, is less affected by the severity of the climate, hardship, and exposure. He is also less liable to become footsore on a trail of rough ice and freezing slush.

bulged or raised the formerly level ice floor along the middle part of the river into a low arch, whose crown, by May 26, stood about 5 feet above its edges or pedal extremities, which were still frozen fast to the shores. In the meantime the excess water, increased by surface drainage due to thaw, unable to find passage beneath the ice, formed broad overflow streams, several feet in depth, coursing on the surface of the ice that formed the limbs of the arch on either side between the crown and the shore. These conditions increased until the 29th, when, at 2.30 p. m., the ice, now visible in the middle of the river only along the crown of the arch, broke or parted transversely and almost bodily moved one-eighth of a mile downstream, when it was stopped by a jam; but at 6.30 it again started and moved about a mile. Soon after this, with increased rise of the river, a general breaking up of the ice took place, and it continued to run more or less steadily until June 6, when the river cleared of it and became navigable. So far as observed, the ice rarely exceeded 2½ feet in thickness, this comparative thinness being probably due to the protecting heavy mantle of snow. Permanent ice usually forms on the river by October 10.

Stoney[a] has described a break-up witnessed by him at Fort Cosmos, on Kowak River, which was probably in most respects similar to that on the Koyukuk just described. In Stoney's description occurs the statement that "the ice suddenly became covered with water, increasing in depth on both sides of the river and decreasing toward the middle." As no reason appears to be assigned for the otherwise peculiar increase of water at the sides and its decrease toward the middle, the writer infers that this phenomenon was due to the ice-arch feature, which seems not to have been recognized by the observer at the time.

The arching feature of the ice, which seems to be characteristic in the breaking up of Arctic rivers and does not attend those in temperate zones—granting a rise in the water at the head of the rivers in both zones—is ascribed by the writer primarily to the presence of permanent subterranean frost, in whose icy grasp the edges and lateral portions of the ice become so firmly welded and held to the frozen earth along shore and the shallow riparian portions of the river bed that it is not released until thawed from the surface downward by almost midsummer suns. In temperate climates, on the contrary, where perennial underground frost does not exist, the longshore ice is the first to give way, and is often replaced by open-water leeways due to the warming and thawing influence of the underground temperature soon after the climax of winter is past.

After the break-up the party proceeded by river steamboat 80 miles up the Koyukuk to Bettles, a new supply post near the sixty-seventh parallel. From this point, commencing June 13, after doing a day's work on Lookout Mountain, the work was continued northward 125 miles, with Peterborough canoes, up a large tributary of the Koyukuk, John River,[a] to its headwaters, thence by a 5-mile portage via Anaktuvuk Pass through the mountains to the upper waters of Anaktuvuk River, the large east fork of the Colville, which flows northward to the Arctic coast. These rivers were descended by canoe and the coast was reached August 15. The ice on the Colville is reported to have broken up July 16.

---

[a] Stoney, Lieut. George M., Naval Explorations in Alaska, U. S. Naval Institute, Annapolis, Md., 1900, p. 52.

After mapping a considerable portion of the Colville delta, the work was continued by canoe 100 miles northwestward along the coast to Smith Bay. Here, owing to the lateness of the season, the stormy weather, and heavy surf incident thereto, the plane-table work was dropped and the journey was continued with Eskimos, who, traveling in walrus-skin boats of native make, were encountered on the journey to Point Barrow. These skin boats were found to be more seaworthy and to sail better than our Peterborough canoes.

September 3 Point Barrow was reached, where it was hoped that passage to the States might be procured on a vessel of the United States Revenue-Marine Service or some whaler; but when it was learned that all such vessels had gone, and that the ice on the ocean was expected to close within a week (September 10 being the usual date), supplies and an open whaleboat were hastily procured and the party proceeded southwestward along the coast, hoping to make connection with a whaler several hundred miles farther south, at Point Hope, where one was expected to touch to leave her native crew. By exceptional good fortune, however, on September 18, at the Corwin coal fields, 80 miles above Point Hope, the steamer *Arctic* was met, which carried the party to Nome, where it landed on September 26. From here passage to Seattle was readily obtained on one of the numerous Alaskan steamers.

Methods of scientific work.—As the Koyukuk did not break up until June, and the expedition, to be successful, was obliged to reach Point Barrow early in September, the season of work was necessarily limited to a period of less than three months, during which 500 miles had to be traveled. Since it was impossible to make more than from 3 to 7 miles a day up the swift waters of John River—and to accomplish even this required the united efforts of the entire party—it became necessary to make almost daily advances, and therefore many mountains could not be climbed that might have afforded more extensive opportunity for observation.

The topographic work was carried on by a combination of the plane table, triangulation, and tachometry, of which an account is given by Mr. Peters on pages 24–25. An independent traverse was carried on by the geologist by means of compass and aneroid to serve as an immediate base for locations in the geologic notes. In this traverse the distances were paced or estimated, and the work was daily connected with the more accurate surveys of the topographer, while from the topographic stations and other established points panoramic photographs with recorded bearings were usually taken to show the character and relations of surrounding rock masses and to supplement topographic sketches.

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[a] Named for John Bremner, pioneer prospector and explorer, who was killed and robbed by a native in the Koyukuk region in 1888. Its native name is Alchichna, meaning *wind river*, so named on account of the fierce wintry blasts that sweep down it from the Arctic side of the divide, through Anaktuvuk Pass. See also note on p. 58.

So far as possible the geologic section was continuously examined, and, where conditions permitted, detailed sketches and diagrammatic notes were made of contacts, structures, mineral zones, and other important features.

ITINERARY AND TOPOGRAPHIC METHODS.

By W. J. PETERS.

Following is an extract from the letter of instructions from the Director of the Survey:

PLAN OF OPERATIONS.

"The object of the expedition under your charge is to execute a reconnaissance survey from Bergman to the Arctic Ocean. The advance will be made by ascending some tributary of the Koyukuk to the divide against which head streams flowing northward to the Arctic Ocean, and thence down such a stream to the Arctic. The return trip will be preferably overland over a route east of that traversed in reaching the Arctic, so as to obtain as much information relating to the interior as possible. If the main branch of the Colville is not descended, however, in going northward, it will probably be advantageous to return along its course. If time or other circumstances do not permit of the overland return, the most practicable alternative route will probably be along the shore via Point Barrow, until the party may be picked up by a vessel of the Revenue-Cutter Service or a steam whaler cruising in the Arctic. If relief should not be obtained from the above sources, the journey should be continued southward until a vessel becomes available or the mining camps are reached.

"As the territory to be traversed is so entirely unknown, you are especially instructed to secure all topographic and geographic information that can possibly be obtained. Sights to all mountain peaks should be taken, distances estimated if intersections are not practicable, and sketches made. In short, no opportunity should be neglected for locating, however approximately, all features that can be seen, especially in view of the fact that it is proposed to prepare a general map of Alaska on the scale of about 40 miles to the inch, and that your party will probably be the only one that will penetrate this region on a geographic mission for many years.

"You are further instructed to afford every facility to the geologist accompanying the party for the prosecution of his special work, and to consult with him in regard to all important emergencies."

In accordance with the above instructions I left Seattle February 9 on the steamer *Victorian*, accompanied by three men—Gaston Philip, assistant, Tom Hunt, and Charles Stuver. It had been arranged that the rest of the party, under Mr. Schrader, should join us at Bergman before the thawing of the ice and snow. We arrived at Skagway[a] February 15, where we were obliged to wait three days on account of the snow blockade on the White Pass and Yukon Railway.

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[a] I wish here to make acknowledgment of the courteous treatment shown us by Mr. E. S. Busby, supervising officer Canadian customs, on presentation of the letter of Mr. John McDougald, commissioner of customs (Canadian), furnished me through the Director of the Geological Survey.

WHITE HORSE TO BERGMAN.

We left Skagway on February 18 and arrived the following day at White Horse, the terminus of the railway. We found the thermometer at 55° below zero, but it rose 30° before we started on our march. On February 21 we left White Horse with 335 pounds, principally instruments and personal baggage, on each of two sleds. The first marches were made very short to avoid the lameness which results from the vigorous exercise of untrained muscles.

Fifty-three road houses are distributed along the 369 miles of trail extending from White Horse to Dawson. This stretch of trail was broad and hard packed by pedestrian, dog, and horse. Considerable heavy freighting was being carried on by horse sled. Below Dawson the trail was narrow, in deep snow, and no wider than a dog sled. From Dawson to Eagle, a distance of 106 miles, there are but four stopping places, while farther down the Yukon they are even less frequent and usually not so well supplied, owing to their remoteness and to the scarcity of patrons. It is 240 miles by winter trail from Eagle to Fort Yukon, and along this stretch are scattered 12 road houses. During the last portion of the journey, from Fort Yukon to Bettles, a distance of 330 miles, there are no cabins, and we were dependent on our own resources. The trail followed there had been made by some parties that preceded us a few weeks, but owing to subsequent snowfalls it was frequently obliterated. This trail followed Chandlar River to Granite Creek and extended up that stream about 20 miles. It then led directly over the summit, crossed the South Fork of the Koyukuk, again ascended a divide, and finally descended into Slate Creek, another tributary of Koyukuk River. From Slate Creek to Bergman there had been much travel by prospectors sledding their summer's supplies up from Bergman.

The whole party stood the low temperature and arduous travel without bad effects. Only woolen garments were worn, which were found to give ample protection while on the march. Wolf robes, one to each man, afforded a warm sleep. Our principal discomfort was due to wet feet. Probably the best footwear for wet snow and overflowing streams are mukluks, or the native boots made on the coast.

Spruce timber was found on all the river bottoms and extending up the tributaries and gulches. Two short stretches, one on the divide between the Chandlar and South Fork of the Koyukuk and the other on the divide between the South Fork and the main Koyukuk, are above timber, but both of these were crossed in less than one day, so that every night we had firewood and some sheltering spruce, though it was small and scattered near the two divides.

Moose tracks were plentiful in the Chandlar Flats, and ptarmigan were occasionally found along the trail, but no other game was seen.

We arrived at Bettles April 14, and were hospitably cared for by Mr. Turner, the agent at this post. The following day we proceeded to Bergman to examine our supplies, which had been sent in the previous season, and found them intact.

RECONNAISSANCE UP ALATNA RIVER.

The party was now divided into two parts for the purpose of reconnoitering a route through the mountains to the Colville waters. Mr. Philip was placed in charge of one of these, and, employing a native guide, ascended Alatna River[a] about 90 miles, to its eastern branch—the Kutuark. On May 5, his provisions becoming exhausted and the increased flow of water betokening a break-up, he turned back, after climbing a mountain near the mouth of the Kutuark, from which the head of this stream appeared to be completely surrounded by high mountains. The northern limit of timber appeared a few miles above the confluence of the streams. Up the western branch the timber extended as far as the valley floor could be seen.

Returning, Mr. Philip reached Bergman May 10. On this trip a few natives on their winter hunt for caribou were encountered.

RECONNAISSANCE UP JOHN RIVER.

On April 23, with the remainder of the party and a native, I started up John River. The first day's march was over the lowlands and directly toward a gap in the mountains. This direct course avoided many large bends in the river, and by night we camped close to the foot of the mountains, having made 16 miles. April 24 we entered the mountains, which rose from 3,000 to 4,000 feet above the valley, and traveled over the frozen stream, with but few cut-offs. On this trip we overtook a native woman, whose four previous camps we had passed. She was subsisting on rabbits that she caught with primitive traps. Camp was made after a march of 10 miles. On April 25 overflows were frequently encountered in the morning, but in the afternoon we were again in deep snow, which was soft, and necessitated the breaking of a trail. This was very tedious work, as the trail had to be traveled several times by all of the party and tramped down with snow shoes before it would support the sled. Sixteen miles were made in this day's march. Natives were seen in the afternoon. On April 26 we were traveling in soft, deep snow, and after going 10 miles were glad to end the weary tramp. On April 27 more natives were seen, who gave us the welcome information that little snow was ahead of us, and but little further on was the bare ice of the frozen stream. In the afternoon another camp of natives was found, and shortly after we ran onto bare ice, which was a great relief to man and dog. The day's march was 17 miles. On April 28 the traveling was on bare ice. Early in the morning we reached timber line and took on a supply of firewood. Grass could be seen protruding through the snow. Wind drifts and marks in the snow indicated very strong wind storms; indeed, we had been warned by the natives last met to go into camp if a blow from the north came on. The pass was visible at the end of a march of 20 miles. I left camp standing and proceeded to explore the pass, which appeared to be short and easily passable. It was impossible to estimate correctly the length of portage for the canoes on account of the frozen conditions. On April 30, being satisfied that the mountains could be crossed through this pass, which I called Anaktuvuk, from the northward-flowing river that it leads to, we started on the return to Bergman, which, with our now lightened sled, we reached on the morning of May 3. During our absence Mr. Schrader had arrived with the rest of the party, according to the original plan. He had found the trail again covered with snow, and to make better progress had thrown away tent, stove, and other articles.

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[a] Called Allen River by Mendenhall in Prof. Paper U. S. Geol. Survey No. 10, 1902.

On the reconnaissance up John River, about thirty natives—men, women, and children—were counted. It is their custom to ascend the tributaries of the Koyukuk in winter to hunt. Caribou is their principal source of food. They never go beyond timber line, and it is very seldom that natives of the north coast come as far south. When the waters run they build rafts and float down, bringing skins to Bergman for trade.

It was now too late to move the cache of provisions with sleds, for the snow was fast becoming soft and the streams were beginning to run. We therefore proceeded to Bergman to await the breaking up of Koyukuk River, and spent the remaining time in starting plane-table work in that vicinity. A base was measured on the river, and four points had been occupied with plane table, when travel became impossible.

At Bergman there were three white men, and but one of these, Mr. Powers, the agent, was there permanently. Not more than half a dozen natives live near the trading post. Mr. Powers succeeded in keeping a horse all winter, feeding him oatmeal and hay, made from a coarse native grass. Several horses were also wintered at Bettles.

The cost of travel from Seattle to Bergman, via Skagway, during the winter, is about $800 per man. The cost of freight from San Francisco to Bergman, by ocean and river steamers, was $150 per ton.

CANOE TRIP FROM BETTLES TO POINT BARROW.

On May 29 the river ice broke, but jammed again in a few minutes. It alternately moved and jammed until June 6, when the river became practically clear of ice. On June 8 the river steamer *Luella* came down from winter quarters and carried the party and outfit up again to Bettles. Preparations were immediately begun for ascending John River, and Lookout Mountain was occupied with the plane table.

A horse was hired, to be used later in packing across the divide, and T. M. Hunt was instructed to provide himself with ten days' provisions and proceed up the valley of John River to good grazing, there to await the arrival of the party, which would work up the river in canoes. The canoes started June 13, when the water was high and very swift. Progress was best made by reaching out from the bow of the canoe, clinging and hauling on projecting bough branches and snags (which is known as "milking the brush"), and aiding the advance by the judicious use of a pole from the stern. High water gradually decreased until June 27, from which time on poling and tracking were more advantageous. Working canoes up this stream necessitated constant wading in the water at a temperature of about 50°. No ill effects, however, were observed in any of the party. Snow had by this time disappeared, except on some of the highest mountains. Occasional stops of one day each were made to ascend prominent points to carry on the mapping. The northern limit of spruce was passed July 8. Beyond this was a thin growth of willows along the stream and its tributaries. On July 9 we passed through a narrow gorge in which the stream was very swift and many bowlders occurred. This was one of the most dangerous parts of the river, and from this point to the camp of July 15 the river was a constant succession of rapids and dangerous rocks, and should not be descended in boats by any one unfamiliar with it. Between camp July 15 and camp July 16 the stream is sluggish. Above the latter point it spreads out, becoming shallow and swift. From camp July 17 the outfit was packed over by the men and horse to a small lake which empties into the Anaktuvuk, and which I have called Cache Lake. Numerous small lakes occur in the pass and along the sluggish parts of the stream.

Grayling abound in the lakes and in the pools that occur in the streams. Several caribou were shot, and signs of goats were frequent on the mountain tops. Everything having been packed over to Cache Lake, on July 22 mail and reports were intrusted to a native, together with the horse, to take back to Bettles.

On July 24 the party started down the Anaktuvuk. About 4 or 5 miles above camp July 28 the mountains end and the stream runs through rolling tundra in a fairly straight course. The channel frequently spreads out and becomes so shallow that wading had to be resorted to in order to lighten the canoes. Many caribou were seen, and one was shot. A small grove of balm of gilead, consisting of about a dozen trees, was passed August 3. Mosquitoes, which had been extremely annoying since June 14, had practically disappeared. Redtop grass was seen growing in many places, particularly at camp August 5. Between camp August 6 and the mouth of the Anaktuvuk willows became thicker, and some were several inches in diameter. Among these were scattered a dozen or two balm of gilead, which, growing to a height of about 30 feet, look gigantic in the absence of other timber. The stream flows through a country that is almost flat, covered with moss, and dotted with small lakes.

From the camp of August 8 the bluffs of the Colville were seen, and on August 9 we ran into that river, which, at the confluence of the Anaktuvuk, is 12 feet deep and about 800 feet wide, with a current running 4 miles an hour. High-water marks were 10 feet above the stage of August 9. The water was fairly clear, but increased in turbidity as we floated down. I believe this turbidity is due to the wash from the bluffs, from which muddy little rivulets continually drip with the thawing of ice. Five miles below the mouth of the Anaktuvuk a short stretch of rapid water (6 miles an hour) occurs, in which bottom was touched at 2½ feet in midstream. Though it is possible that deeper water might have been found, I doubt if it would have been more than 4 feet at that stage. Between the rapids, shown on the map accompanying this report, the current was not over 2 miles an hour, and in them it was not greater than 6 miles. The rapids shown are all very gentle, and average not more than 100 yards in length. Four feet of water was the minimum found over all of these swift places, except the one opposite Sentinel Hill,[a] where the depth was not over 3 feet. At high water, which probably occurs in June, all of these small rapids would disappear. Good grass was found on "Coal" Bluffs.

At Sentinel Hill the Colville divides and thence flows in two or more channels. The one nearest the bluffs on the western side of the valley is the deepest. Twenty-four miles below Sentinel Hill the end of the bluffs is reached, and the river, containing four islands, runs in one channel through a flat whose surface is 10 to 15 feet above sea level. The river gradually widens from 1,100 feet at the end of the bluff to 5,000 feet at the head of the delta. The head of the delta, where a very small tide is perceptible, was reached August 13. The main channel has a course N. 30° E. magnetic, and is the one farthest to the right, or the most easterly one. There was not sufficient time to follow this to the sea. It is over 12 feet deep at the head of the delta and apparently continues unbroken to the ocean. This is the only one that would be navigable for river steamers. In the endeavor to find the native village of Nigaluk, several channels were explored and the delta was roughly mapped, but it being evident that we had passed the westernmost or left-hand channel, on which Nigaluk is probably located, and not having time to return, we put out to sea. I estimated the delta to be about 20 miles wide.

Tracks of caribou were numerous on the delta, and later I learned that caribou frequent the coast to avoid the clouds of mosquitoes in the interior. On August 18 we left the delta and its mud flats and followed the coast, which varies from a low beach to ice bluffs 10 to 20 feet high. A camp of natives was seen on the delta, but little information could be obtained from them. They appeared friendly, but were not communicative. On August 20 these natives overtook us, followed by about a dozen umiaks, each containing from three to six persons—men, women, and children—on their way to Point Barrow. As they appeared to weather seas that we dared not attempt in our canoes, and as our time was getting short and storms were brewing, I decided to induce these natives to take us in their boats.

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[a] An isolated hill, so named on account of being a prominent landmark.

Along the coast we were dependent for firewood on the ocean drift. This is abundant in places, but at several camps there was barely sufficient for our need. It does not compare in quantity with that found on the southern coast of Seward Peninsula. Among the logs, which were principally spruce, were noticed a redwood and one or two pines. Drinking water is to be had almost everywhere along the coast, even on the small islands, provided they are covered with moss. It is, however, often brackish.

After losing several days by storms, we arrived at Point Barrow on the evening of September 3, and at Cape Smyth about midnight. Mr. Brauer, agent of the whaling station here, gave us a warm welcome. A steam whaler had left a day or two before, and as no more vessels were expected to pass the point, he supplied us with a whaleboat with which to sail to Cape Hope, where he thought we would likely catch a vessel bound home. We started on September 5, as there was danger of the ice pack being driven in if the wind shifted to the northwest or north.

The coast from Cape Smyth to Cape Beaufort is very low, with a sandy beach, back of which bluffs rise rarely to a height of 75 feet. No high land could be discerned in the interior. Except when prevented by the storms of September 6, 9, 11, 12, and 13, we were constantly working toward Cape Hope, sailing, rowing, or towing.

In the afternoon of September 18 we sighted the funnel and masts of a steamer lying off the coal veins east of Cape Lisburne, and about dark, there being a perfect calm, this steamer, which proved to be the *Arctic*, was boarded. She was taking on a load of coal for Nome, and on the night of September 21 she steamed away, arriving at Nome September 26. Here one of the regular steamers was taken for Seattle, where the party was disbanded.

METHODS OF TOPOGRAPHIC WORK.

At intervals of about 10 miles prominent points adjacent to the river were ascended for topographic sketching on the plane table. Two signals, usually stone cairns about 6 or 7 feet high, were left on each of these points to mark the ends of the base which was to be used in determining the distance to the next station. This next station was usually selected first, so that the base might be laid off at right angles to a line joining the two stations, or as nearly so as the shape of the summit would permit. The direction of the base was always projected on the plane-table sheet to permit of the measurement of the angle between it and a line to any other station that might be occupied. The length of the base was from 300 to 600 feet, and was chosen with regard to the estimated distance and direction of the next station so as to subtend an angle of about 22 minutes, which was measured with the micrometer screw of the alidade.

Between stations a traverse of the river was made with prismatic compass and stenometer. The plat of the traverse was transferred to the plane-table sheet and fitted to the located points. The orientation of the plane table was controlled by the azimuths, determined with the theodolite when necessary.

The method of plane-table locations was followed from Bergman to a point 20 miles beyond the summit, and, judging from intersections on points on either side of the route, it was satisfactory and sufficiently accurate for the publication scale of the accompanying exploration map. The compass and stenometer were used from a point 20 miles beyond the summit to the end of the traverse, on the Arctic coast.

PREVIOUS EXPLORATIONS.

HISTORICAL SKETCH.

Soon after the discovery of America interest was awakened in, and attempts began to be made to find, a northwest passage from the Atlantic to the Pacific Ocean, and these led directly or indirectly to explorations of Alaska and adjacent regions. The discovery of the northwestern side of America, and especially of the Arctic coast of Alaska, was preeminently the work of the English and the Russians.

For the benefit of the reader who may desire to extend his knowledge on this subject, a list of works from which much of the information here compiled has been drawn is given at the end of this chapter. Though the following sketch aims to note the more important of these discoveries and explorations, it does not attempt to be exhaustive.

Samuel Hearne,[a] of the Hudson Bay Company, reached the Arctic Ocean as early as 1770 by way of Coppermine River, in longitude approximately 110°. His journey was considered as demonstrating the practicability of reaching the coast by this route and means of travel, and, what was of much greater importance, the absence of any waterway connecting Hudson Bay with the Pacific Ocean.

In 1778 Captain Cook's expedition,[b] composed of the vessels *Resolution* and *Discovery*, in search of the northeast passage, explored the northwest coast from Norton Sound to latitude 70° 41′, a little north of Icy Cape, where they were obliged by the ice pack to turn back. The conclusion reached at this time (and the correct one it afterwards proved to be) was that no passage existed south of latitude 65°, and that it must be sought north of Icy Cape.

In 1789 Sir Alexander Mackenzie, a member of the Northwest Trading Company, descended to the mouth of the great river which bears his name. In its delta he located Whale Island, so named by him from the large number of white whales observed at this point. He also made observations on the tide of the Arctic Ocean. His descriptions and locations of channels were later found by Sir John Franklin to be very complete and accurate.

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[a] Hearne, Samuel, A Journey from Hudson's Bay to the Northern Ocean, Dublin, 1796, p. 162. See also Barrow's Arctic Regions, p. 300.

[b] Cook's Voyage to the Pacific Ocean, 3 vols., London, 1785, vol. 2, pp. 446-465.

In the year 1815 Lieutenant von Kotzebue,[a] of the Russian Navy, penetrated Bering Strait and explored the sound which bears his name, together with the northwest region as far north as Cape Lisburne. After this time we have no record of this part of the coast until the voyage of Captain Beechey, who explored the larger part of the entire Arctic coast in the years 1825–1828.

In 1826, under the auspices of the Earl of Bathurst, Sir John Franklin descended the Mackenzie to its mouth and surveyed the coast line to the west as far as Return Reef, near longitude 149° W. Acting in conjunction with Franklin, Captain Beechey, of the *Blossom*, had entered Bering Strait and sent a boat expedition in charge of Master Thomas Elson, which in the same year explored the coast as far north as Point Barrow, the northwesternmost point of the American continent.[b] The exploration of the intervening distance, consisting of 160 miles of coast line, between the points reached by Beechey and Franklin on the west and east, respectively, was subsequently completed, and the north coast of the continent was outlined about ten years later, in 1837, by Dease and Simpson, by whom many of the natural features along this section of the coast were named.

In his westward advance beyond the mouth of the Mackenzie, Franklin was the first to round the great chain of the northern Rocky Mountains, consisting here, as he perceived from the coast, of several parallel ranges. These are the Richardson, Buckland, British, Romanzoff, and Franklin mountains. According to Dease and Simpson the portion of the Rocky Mountains visible from the coast does not terminate, as conjectured by Franklin, in the Romanzoff chain, but after a brief interval the Romanzoff Mountains are succeeded on the west by another chain, less lofty but equally picturesque, which was named by Dease and Simpson the Franklin Mountains. These mountains present a precipitous front to the coast.

In the days of these earlier discoverers the above-named parallel ranges, rising from 2,000 to 3,000 feet, were apparently supposed to be the final termination of the Rocky Mountains extending northward from the United States and British Columbia. The great extension of the main axis to the west along the sixty-eighth parallel and its development into a range nearly 100 miles in breadth and 6,000 feet high were unknown. Not until the performance of the work forming the basis of this report was a correct idea of this obtained.

At the same time that Franklin was conducting his discoveries westward along the coast, a detachment of his party proceeded from the mouth of the Mackenzie eastward, connecting their explorations with those previously made by him near the mouth of Coppermine River.

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[a] Dall, W. H., Alaska and its Resources, London and Boston, 1870, pp. 329–330.

[b] Voyage of Captain Beechey to the Pacific and Behring's Straits, London, 1836.

In the meantime, the Russians, having obtained a foothold in Bering Sea and on the coast to the south, pushed up the Kwikpak, or lower Yukon, which Malakoff,[a] a creole, explored in 1838 as far north as Nulato, below the mouth of the Koyukuk, where he built a small post for the purpose of trading with the natives. In 1842 Lieut. A. Zagoskin, of the Russian Imperial Navy, explored the Koyukuk for 50 miles or more above its mouth, but explorations on the upper Koyukuk were not made until some time after much of Yukon River had been ascended and explored.

While the above explorations were being conducted along the coast during the first half of the century, in the interior the pioneers of the Hudson Bay Company, representing the English, pushed still farther northwestward from their remote outposts on the Mackenzie into regions then unknown, in quest of new fields in which to ply their fur trade. Liard and Dease rivers were explored, and in 1842 Robert Campbell descended the Pelly to its confluence with the Lewes, where Fort Selkirk was subsequently established in 1849. Also in 1842 J. Bell[b] crossed the divide from the Peel River drainage into that of the Porcupine, and in 1847 McMurray descended the Porcupine to its mouth and founded Fort Yukon, on the banks of the river of this name, under the Arctic Circle, whence trade was opened with the natives. Not until two years later, however, when Campbell descended the Yukon from Fort Selkirk, was it learned that the two posts were on the same stream. The river was not ascended to this point from the western coast, however, until 1863, when the trip was made by Ivan Simonson Lukeen, an employee of the Russian American Company, and the Yukon of the English and the Kwikpak of the Russians were found to be identical. Not until then was it fully realized that the Yukon flowed into Bering Sea instead of northward into the Arctic Ocean by way of the Colville, as had been supposed, and as was represented on the maps of our school geographies until and even subsequent to that time.

In 1849 Lieutenant Pullen, of H. M. S. *Herald*, made a boat voyage from Bering Strait to the Mackenzie, and in 1850 the boats of the *Plover*, starting from Cape Lisburne, reached Bailey Island, in longitude 127°. In 1850–1854 Commander Captain McClure, of H. M. S. *Investigator*, proceeded from Bering Strait to Banks Island and Lancaster Strait, where the crew finally abandoned the ship in the ice, and by walking over the ice to Beechey Island discovered and made the northwest passage. Also, in 1850 and 1855, Capt. R. Collinson, of the *Enterprise*, sailed from Bering Strait to near King William Island, in Victoria Strait, whence, being short of coal, he retraced his course to Bering Strait. In 1852–53 the *Plover*, in command of Captain Maguire, wintered at Point Barrow, in Moores Harbor, whence members of the expedition made journeys southwestward to Tasiak River and eastward along the coast to Return Reef, in longitude 150°, Maguire himself going as far as Smith Bay.

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[a] Dall, W. H., Alaska and its Resources, London and Boston, 1870, p. 48.

[b] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 104.

In the autumn of 1860 Robert Kennicott,[a] crossing from the Mackenzie, arrived at Fort Yukon, and in the spring of 1861 descended the Yukon as far as Small Houses.

In 1865 J. T. Dyer and R. D. Cotter,[b] in connection with the Western Union Telegraph expedition, are reported to have made a very creditable exploration of the country between Norton Bay and the mouth of Koyukuk River, on the Yukon.

In 1866 Ketchum and Laberge, explorers for the Western Union Telegraph expedition, ascended the Yukon to Fort Yukon with Lukeen, and later, in 1867, continued their investigations up the river as far as Fort Selkirk.

In 1867 Dr. W. H. Dall, at first in connection with the Western Union Telegraph expedition and later at his own expense, in descending the Yukon, visited the Koyukuk. Though Dall's work was necessarily of a pioneer character, his contributions to our knowledge of the interior of Alaska were very important, as they gave the first clue to the geology of the Yukon Basin.

Astronomic observations made at Nulato by Capt. C. W. Raymond, who ascended the Yukon in 1869, materially aided in more accurately locating the mouth of the Koyukuk, also the position of the upper Koyukuk, which until recently rested largely upon the astronomic determinations subsequently made by him in the same year at Fort Yukon.

The first whaler is reported to have entered the Arctic Ocean in 1848, and since then whaling has there been an important industry.

From 1881 to 1883 a signal service station, in charge of Lieut. P. H. Ray, of the United States Army, was maintained at Point Barrow, which was one of the polar magnetic stations located by international agreement. The report of this expedition and station gives statistics and valuable tables containing results of meteorologic, astronomic, magnetic, zoologic, ethnologic, geographic, and some marine observations. In making inland explorations, a part of the upper course of Meade River was mapped and the Meade River Mountains were discovered.

In 1884 additional valuable information on northwest Alaska, including the Kowak River region, was gathered on the cruise of the *Corwin*, by Capt. M. A. Healey and officers of the United States Revenue Service. Their work was subsequently continued by various other revenue cutters, some of which have visited the northwest coast of Alaska almost every year. Of these visits the most notable is probably that of the U. S. revenue cutter *Bear*, which sent out the winter overland expedition of

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[a] Smithsonian Reports, 1861, pp. 39-40; 1864, p. 417.

[b] Dall, W. H., Alaska and its Resources, London and Boston, 1870, p. 277.

Lieutenant Jarvis and Drs. Call and Lopp to Point Barrow, for the relief of the whalers in the Arctic Ocean. These investigations, including the explorations of Kowak River, by Lieut. J. C. Cantwell, and of the Noatak, by Asst. Engineer S. B. McLanigan, of the *Corwin*, were continued in 1885.

In 1885 Lieut. H. T. Allen, of the United States Army, leaving the Yukon by way of the Tozikakat route, reached the Koyukuk near the Arctic Circle and ascended it to near the sixty-seventh parallel. In the same year a detachment of Lieutenant Stoney's expedition crossed from his camp on the Kowak to the lower Koyukuk by way of the Dakli.

During the winter and spring of 1886 further explorations were made on the Arctic slope by Lieut. W. C. Howard,[a] who, on a trip that was productive of important results, crossed from Stoney's camp on the Kowak to the head of the Colville, Chipp (Ikpikpuk) River, and thence by way of the head of Dease Inlet to Point Barrow. Howard's trip showed that a low pass leads through the mountains from the Kowak to the Noatak; that another leads from the Noatak to the upper waters of the Colville, and that on the upper Colville in the region of longitude 156° W. the mountains are succeeded on the north by an undulating country, in which the river has a winding course, with steep banks. Farther northward, down Chipp (Ikpikpuk) River toward the coast, the undulating country is reported to give way to a "dead level waste of tundra."

To the east, Mr. R. G. McConnell, of the Canadian geological survey, descended the Mackenzie in 1888 on geologic reconnaissance work as far as the mouth of Peel River, near the sixty-eighth parallel, whence he crossed by way of the Porcupine to the Yukon.

In 1889 Mr. I. C. Russell, who as geologist accompanied the Alaskan-Northwest Territory boundary survey parties sent out by the United States Coast and Geodetic Survey, ascended the Yukon from its mouth to its source, and soon after published valuable geologic and geographic notes on his observations made along the route.

In 1890 the Arctic coast opposite Herschel Island was visited by Mr. J. H. Turner, of the United States Coast and Geodetic Survey, in connection with the international boundary survey between the Canadian Northwest Territory and Alaska. On this trip Mr. Turner made a geographic reconnaissance from the Porcupine across the Davidson Range, following the one hundred and forty-first meridian, which resulted in a material contribution to our knowledge of the mountains and country in this region.

In 1892–1894 Mr. Frank Russell, under the auspices of the Iowa State University, descended the Mackenzie, principally to make ornithologic and ethnologic investigations.[b]

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[a] Stoney, Lieut. George M., Naval Explorations in Alaska, U. S. Naval Institute, Annapolis, Md., 1900.

[b] Russell, Frank, Explorations in the Far North, published by the University of Iowa, 1898.

In 1896 extensive geographic and especially geologic contributions were made to our knowledge of the Yukon Basin by a United States Geological Survey party in charge of Mr. J. E. Spurr,[a] who descended the river and mapped the gold- and coal-producing districts.

Owing to the extended interest taken in Alaska by reason of the Klondike discoveries, during the years 1897 and 1898 the Koyukuk[b] was visited by 1,200 or more prospectors, miners, and adventurers, many of whom ascended the river by steamboat nearly to the Arctic Circle. Some of these subsequently explored and prospected various tributaries as far up as latitude 67° 30′. Many spent the winter of 1898–99 here. During approximately the same period, 1897–98, some of the prospectors who had ascended the Kowak crossed the divide to the northeast and reached the Koyukuk by way of the Alatna.

In 1899 a United States Geological Survey party,[c] conducting a reconnaissance traverse from Fort Yukon to Nulato, ascended Chandlar River, and, crossing from its headwaters, mapped the Koyukuk from near the head of its middle fork, near the sixty-eighth parallel, to the mouth of the river at the Yukon.

During the summer of 1900 a party of prospectors crossed the divide between the head of the Koyukuk and the Arctic drainage by way of Dietrich River and descended the Arctic slope along the one hundred and fiftieth meridian to a point probably a little north of the sixty-ninth parallel. From a personal interview with members of this party the writer infers that the country is passable by pack train. It is, however, mountainous and is reported to contain some glaciers of considerable size, but these are probably valley glaciers only. To the east of this the country has been traversed by deserters from whaling vessels at Herschel Island, who made their way in a destitute condition from the coast to the Yukon by way of Chandlar River. From accounts given by some of these men in a personal interview, the writer obtained the impression that this part of the region is largely a waste of rugged mountains, containing some glaciers, which are probably confined to the heads of the valleys.

During the season of 1901 a geologic reconnaissance survey was also made from Fort Hamlin, on the Yukon, by way of Dall, Koyukuk, Alatna, and Kowak rivers, to Kotzebue Sound by a party in charge of Mr. W. C. Mendenhall.[d]

During the years 1901 to 1903 the region lying between the Colville Basin and the international boundary was visited, it is reported, by S. J. Marsh and T. G. Carter, two prospectors who landed at Camden Bay in the fall of 1901, and,

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[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898.

[b] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 458.

[c] Op. cit.

[d] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper U. S. Geol. Survey No. 10, 1902.

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1831. Beechey, F. W. Narrative of the voyage of the *Blossom* to the Pacific Ocean and Bering Straits. London.

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1870. Dall, William H. Alaska and its resources. London and Boston. 8°. xii, 628 pp., 13 pl.

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POPULATION AND CONDITIONS.

ON THE KOYUKUK.

Natives.—So far as can be judged, there are about 100 native inhabitants on the upper Koyukuk. The United States census for 1900 places the population of Peavey village, near the South Fork of the Koyukuk, at 35. The settlements of the Koyukuk natives, each consisting usually of a few cabins and tents, are sparsely scattered along the river from below the Arctic Circle to the sixty-seventh parallel of latitude. They are generally located at the mouth of some tributary stream, as in the case of Alatna River, Pickarts Creek, and Kanuti River. Their village at Bettles, which is larger than most others, forms an exception to the above rule, and exemplifies the disposition of the natives to remain near a trading post and the abode of white men.

At the post the natives are frequently employed by the whites for boating, sledding, and other work, for which service they receive provisions and clothing, which, added to what they get of game and fish, make up their living. They take but little interest in prospecting or mining. Apart from the partial sustenance they procure at the post, their chief source of food and clothing is the wild Alaskan reindeer or caribou, bear, salmon, whitefish, rabbits, grouse, and ptarmigan.

The Koyukuk country is also visited by the Kowak natives from the northwest, a more hardy and industrious race than the Koyukuks.

Whites.—After the exodus of the thousand or more inexperienced adventurers who in the Klondike rush reached the upper Koyukuk in the fall of 1898, wintered there, and disappeared from the country almost with the ice when navigation opened in the following spring, about a hundred sturdy men, mostly prospectors and miners who had arived with the influx the preceding fall, remained. Stimulated by the discovery of placer gold, they continued to prospect and began to mine some during the summer and engaged to some extent in development work during the following winter. In the meantime, especially in the months of February and March, 1900, as the reports of the presence of gold became authenticated, many people from various camps along the Yukon were attracted thither. This materially increased the mining activity of the district, which in a general way has continued to the present time; so that in 1901–2 about 200 white people, mostly miners and prospectors, wintered there, and at present[a] (1903–4) they number about 350, the most of whom are prospecting or doing development work about the mines. Besides the people who winter there, many others reside there during the summer only, while working their claims. Since the discovery of gold the wage for the district has been $12 a day. Ground that will not yield this amount or more is not worked. Board is $6 a day.

Transportation and means of travel.—Since 1900 there have been two supply posts[b] in the country, Bergman and Bettles, both operated by the Northern Commercial Company, successor to the well-known Alaska Commercial Company. Of these posts, the lower and usually the best stocked is Bergman, at the head of steamboat navigation, near the Arctic Circle, and about 450 miles above the mouth of Koyukuk River. At high water, however, in both spring and fall, steamboats ascend with freight to Bettles, near the sixty-seventh parallel, about 80 miles above Bergman. From Bettles, which has become the leading distributing point for the country, the supplies are conveyed to the various mining camps, about 75 miles farther up the river, by rowboat during the open season, or, preferably, by dog sled in the winter. The country is also reached by pack train from the Yukon in summer, by way of Chandlar River from Fort Yukon and by way of Dall River from near Fort Hamlin, the distance in each case being about 150 miles. Pack horses have been used to some extent during the last few summers, both for packing and for working at the mines, but the heavy snowfall renders the horse unfit for winter use. A shorter route than either of the above, leaving the Yukon at a point about midway between the Dall and the Chandlar and about 100 miles from Coldfoot direct, is now being investigated.

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[a] Information on present (1903) conditions in the district has been contributed by Mr. L. M. Prindle, a member of the Survey, to whom it was recently furnished by miners en route from there to the States.

[b] Besides these, the company keeps a branch post at Coldfoot.

The principal post-office is at Bettles, but mail is also distributed from Bergman and from Coldfoot, at the mouth of Slate Creek. The judiciary of the district, consisting of United States commissioner, probate judge, coroner, and recorder, is located at Slate Creek, near the center of the mining region. Since early in 1901 these offices have been held by Judge D. A. Mackenzie, a former citizen of Seattle, and one of the pioneers of the Koyukuk country.

The placers.—The gold placers are shallow deposits, well suited for development by men of moderate means, who are able and willing to work. No one, however, should go to this country intending to mine without taking with him a year's supplies, commonly known as a "grub stake," or its money equivalent, about $1,000. The mining period is confined to about 2½ months in summer.

The placers now being worked extend over a large area, but occur chiefly on the middle drainages of the Middle and North forks of Koyukuk River, where they embrace a score or more creeks with their tributary gulches, some of which have been discovered recently. The gold is coarse. The yield of the district to date, as shown on page 102, is about $717,000.

ON THE ARCTIC COAST.

Natives.—With the exception of about a dozen white persons at Cape Smyth, near Point Barrow, and some at Point Hope, the bleak Arctic coast of northern Alaska is inhabited only by the Eskimo. From the international boundary to Point Hope, through a distance of 800 miles, the native population aggregates about 1,500 persons. Their settlements are far apart. The principal ones are those of Point Hope, Cape Smyth, Nuwuk at Point Barrow, Nigaluk at the mouth of the Colville, and Barter Island about 150 miles farther east. There is also a settlement at Herschel Island, east of the international boundary, and one in the Mackenzie River delta. There is yearly communication between all these points. The census of 1900 credits Point Hope village with a native population of 314, and the settlement of Cape Smyth, probably including Nuwuk,[a] with a population of 623. That of Nigaluk, at the mouth of the Colville, also probably amounts to about 200. There are also smaller settlements or single huts at points along the coast, as at Wainwright Inlet and Icy Cape, which are occupied in winter but generally vacated in summer.

The principal food supply contributed by the sea is derived from the whale, walrus, seal, polar bear, and some small fish. Salmon, herring, smelt, and other small fish are found in the inlets and rivers. During the summer season there are large numbers of geese and ducks. The principal land quadrupeds are Alaskan wild reindeer or caribou, brown and black bear, wolverine, marten, wolf, hare, lynx, fox, beaver, muskrat, and lemming. Of these, the most important for food and clothing, and fortunately the most abundant, is the caribou, whose migrations the natives follow. Berries and roots are also used for food by the natives.

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[a] Nuwuk, meaning in Eskimo "the point," is the name of the native village on Point Barrow proper, while the main settlement of the white people, where are the trading post, mission, and post-office Barrow, is 9 miles southwest of Point Barrow, at Cape Smyth, to which the name Point Barrow is generally though somewhat incorrectly applied.

As the coast region is destitute of timber, affording only a few dwarfed willows at distant points along the rivers and inlets, the principal fuel of the natives is driftwood, most of which has been discharged into the ocean by the larger arctic rivers, whose headwaters lie in forested regions. This is fairly well distributed along the coast, but is not so abundant as often supposed.

The Alaskan Eskimos, so far as seen by the writer, are not the dwarfed race of people they are often depicted. The men will probably average nearly 5½ feet in height and 150 pounds in weight. They are generally robust, muscular, and active, inclining rather to angularity than to corpulence. The face may be described as flat, broad, and rounded, with high cheek bones. The eyes are brown or dark and the hair is black. As a people they are relatively intelligent and industrious and appear to be reasonably honest and moral. They are hospitable, good-humored, and cheerful, apparently free from care, and generally patient and tactful in manner. Their feelings have been described as lively but not lasting, and their temper is frequently quick but placable. The conjugal and parental affection is strong. Though thankful for favors, their gratitude is of short duration.

Owing to its mixture with that of representatives of other races who reach the arctic regions, principally on whaling vessels, the blood of the Alaskan Eskimo is rapidly losing its purity. Children of pure Eskimo blood are reported to be very few.

Whites.—There are at present about a dozen white persons living at Point Barrow. There is a mission school here at present, in charge of Doctor and Mrs. Call. A trading post, maintained here by the Cape Smyth Whaling and Trading Company for purposes of trade with the natives and whalers, is now in charge of Charles Brauer. The keepers of the post engage to some degree in whaling, in which they employ the natives. Early in April the whaling parties proceed by dog sled 10 or more miles out over the ice to the open sea, where they pursue their calling in open skin boats.

Point Barrow is almost annually visited by vessels of the United States Revenue Service and by various whaling vessels. Ten of the latter are reported to have called there during the summer of 1901. Whaling in this part of the Arctic Ocean has been carried on with varying success by several companies during the last half century, but is now reported to be on the decline. The pursuit is hazardous, as the vessels are often caught in the ice pack.

In 1901 effort was being made by a Japanese to establish a small trading post at the mouth of Staines River, near the one hundred and forty-sixth meridian.

Transportation and means of travel.—Transportation and travel in this barren region is principally by native skin boats along the coast and streams during the short open summer, and by dog sled over the snow and ice in winter; though the north coast Eskimos sometimes make trips into the interior from the mouth of Chipp (Ikpikpuk) River southward to the head of Colville, Noatak, and Kowak rivers. Their knowledge of the country in general is not definite beyond a distance of 40 or 50 miles from the coast.

The native skin boats, or umiaks, are usually made of walrus skin. Being light, flat-bottomed, and responsive to sail, they are admirably adapted for use in the shallow waters of the deltas and tidal mud flats so characteristic of the Arctic coast, and for small craft are very seaworthy.

TABLE OF DISTANCES.

The following table, prepared by Mr. Peters, is here inserted to afford an idea of approximate distances along the route of travel.

Distances up John River.

Mouth of John River	0
Fool Creek	51
Hunt Fork	92
Rocky Gorge	106
Anaktuvuk Pass	120
Cache Lake	125

Distances down Anaktuvuk and Colville rivers.

Cache Lake	0
Canyon	43
Small grove Balm of Gilead	54
Ice field	63
Two native huts	101.5
Mouth of Anaktuvuk River	114
Rapid[a]	117
Rapid[a]	119.5
Rapid[a]	121
Sentinel Hill	140
Rapid[a]	143
Rapid[a]	147
Rapid[a]	157
Ocean Point	164
Head of delta	192.5
Arctic Ocean	212

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[a] These rapids are short stretches of the river, running about 6 or 7 miles an hour, with no rough water.

Distances along coast from Colville River to Cape Smyth.

Middle channel of Colville River	0
West channel	17
Cape Halket	67
Pitt Point	90
Simpson Cape	137
Tangent Peak	189
Point Barrow	198
Cape Smyth	207

GEOGRAPHY.

LOCATION AND GENERAL FEATURES.

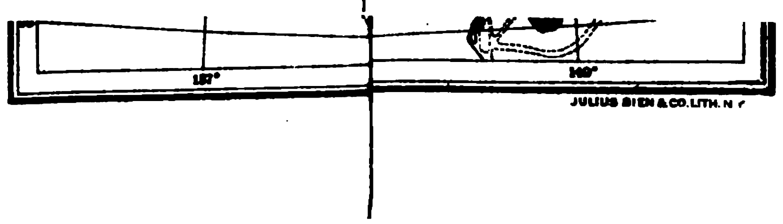
The region here considered, as shown on the outline map, Pl. I, lies in northern Alaska, mainly in its middle part. The area covered by the detailed maps (Pls. II and III) trends in a nearly northward direction from the sixty-sixth parallel of latitude approximately along the one hundred and fifty-second meridian to about the seventy-first parallel at the Arctic coast, a distance of about 400 miles. The maps are based entirely on observations made during the present exploration along Koyukuk, John, Anaktuvuk, and Colville rivers, except that to these have been added some notes of observations made by Mr. T. G. Gerdine and the writer in the Koyukuk district in 1899.

Geographically the region consists of three well-marked provinces—the mountain or middle, the Koyukuk or southern, and the Arctic slope or northern.

Orographically the mountain range, forming the middle province, is regarded as a northwestern continuation of the Rocky Mountain system of the United States, which, extending northwestward through Canada nearly to the Arctic Ocean, bends abruptly to the west beyond the Arctic Circle and trends nearly westward across northern Alaska, forming the great trans-Alaskan watershed between the Yukon Basin on the south and the Arctic Ocean on the north. In its northward and finally westward course the range forms a prominent feature of the "concentric" orography of Alaska, and embraces in its southward-facing curve the great basin of the Yukon and the well-known, but not always well-defined, Yukon Plateau.

From its character and relation to the range, it seems probable that the gently rolling plain bordering the mountains on the north and sloping gently to the Arctic Ocean may be physiographically correlated with the Great Plains in western United States, while the basin of the Yukon corresponds to the great Interior Basin of the West, lying between the Rocky Mountains and the Coast Range.

In their trend across Alaska the mountains agree with those in the Canadian territory adjacent to the east, which extend nearly to Mackenzie River. In the



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region north of the mountains, both in Canadian territory and in Alaska, the valleys trend northward toward the Arctic coast, while those on the south trend southwestward toward the Yukon.

Considering the country more in detail, we may note that the line of profile extending through the region as a whole, in a north-south direction (see Pl. II), beginning on the south, at the sixty-sixth parallel, traverses for the first 120 miles of its course an undulating country whose low, rounded hills attain elevations of from 1,000 to 3,000 feet. It then crosses a rugged range of mountains 100 miles wide and about 6,000 feet high, whence it descends steeply to the elevation of 2,500 feet at the inland edge of a gently northward-sloping plateau or rolling plains country (Pl. IV). It then traverses this rolling plain for 80 miles, and thence passes for about 80 miles through a nearly flat, tundra country or coastal plain to the Arctic coast.

To facilitate description each province will be treated separately.

MOUNTAIN PROVINCE.

The most striking is the middle or mountain province, which, as noted, consists of an inland range of rugged mountains trending east and west across the field between latitudes 67° 10′ and 68° 25′, as shown on the topographic map, Pl. II. These mountains here have a width of about 100 miles and an average elevation of about 6,000 feet.

It is unfortunate that the term Alaskan has already been applied to a local range lying south of the Yukon, as that name would seem to be the most fitting term by which to designate this portion of the great Rocky Mountain system, which here extends east and west entirely across the northern part of the Territory. That these mountains are regarded as a northwestward continuation of the Rocky Mountain system has been noted. and the term Rocky Mountains has been broadly applied to them on the map.

That portion of the main range lying between the international boundary and Mackenzie River has been called the Davidson Mountains, while to the several small groups on the north, between the main range and the coast, and extending from the one hundred and thirty-eighth to the one hundred and forty-eighth meridians, the names Richardson, Buckland, British, Romanzoff, and Franklin have been applied. They are all probably more or less closely connected with the main range, from the northern side of whose great bend to the southwest between Mackenzie River and Colville River they seem to branch. So far as known they trend in a general northwestward direction, but have a somewhat imbricated relationship, each group tending to overlap the inland part of the one next to the west. They seem to represent the northward dying out of the range near the Arctic coast. If they are considered a part of the range in the region of the one hundred and forty-seventh meridian, they give to it a breadth of about 210 miles. In elevation these groups lie generally between 2,000 and 4,000 feet, while the height of the main range near the international boundary is from 5,000 to 7,000 feet. From this point, with but slight if any decrease in elevation, the range continues westward to the one hundred and fifty-third meridian, beyond which, in the region at the head of Colville and Noatak rivers, it diminishes in height, and seems to divide into two parts or ranges. Of these, the northern range, continuing westward, terminates in the low mountains and abrupt sea cliffs of Paleozoic rocks at Cape Lisburne (see Pl. V and fig. 1), while the southern forms the divide between Noatak and Kowak rivers.

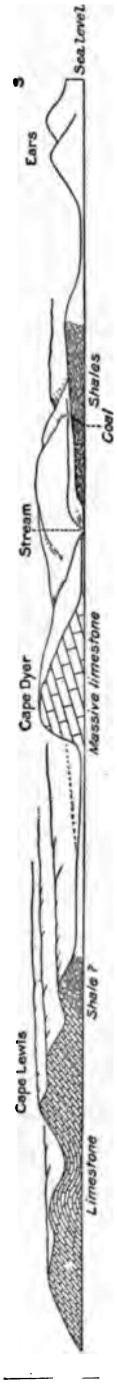

FIG. 1.—Sketch section of supposed Paleozoic rocks on the coast south of Cape Lisburne.

ENDICOTT MOUNTAINS.

GENERAL FEATURES.

It is probably to the range between Noatak and Kowak rivers, as seen from Lookout Mountain, on the Koyukuk, that Allen in 1885 gave the name Endicott Mountains. Though the name appears on Allen's map,[a] and is referred to in the text of his report, it is not known to have come into use or to have appeared on any of the numerous succeeding Alaskan maps. Allen refers to the mountains of this region as comparatively low, and says the highest are the Endicott Mountains, between Koyukuk and Kowak rivers, which, extending northward, were supposed to contain the headwaters of Colville River. The highest peaks were estimated at 4,000 feet. As printed on Allen's map, however, the term is given a broader significance, applying to practically the entire portion of the range embracing the headwaters of the Koyukuk and the sources of the drainage ways which flow in an opposite direction into the Arctic Ocean, between the one hundred and forty-fifth and one hundred and fifty-fourth meridians. As the term embraces and seems fittingly to apply to all that part of the range considered in this report, it will here be retained, and the mountains will be referred to in this report as the Endicott Mountains.

Where crossed by the Geological Survey party the range lies between the rolling, hilly country of the Koyukuk Basin on the south and a very gently undulating plateau country on the north. On the south the rise from the rolling country to the mountains is by foothills, but rapid. On the north the mountains break off abruptly, much as they do along the edge of the Great Plains in western United States.

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[a] Allen, Lieut. H. T., Reconnaissance in Alaska, 1885, Washington, Government Printing Office, 1887.

Pronounced faulting and uplift are evidenced by marked deformation of the strata and in some places by fault scarps miles in extent.

The comparatively regular southern edge of the range trends approximately east and west, in latitude 67° 10′, while the northern edge, where it was crossed, in the region of Anaktuvuk River, latitude about 68° 25′, presents a concave front to the north, as shown on the maps (Pls. II and III). This crescentic feature is repeated by several low concentric ridges in the Anaktuvuk Plateau to the north. These seem to have been formed by a part of the same orographic uplift as the main range, for they lie parallel with its front and grow weaker and finally die out northward with increase of distance from the seat of maximum uplift.

West of the Anaktuvuk the crescentic front of the range soon gives way to a more nearly westward trend, bearing in the direction of Cape Lisburne. To the east of the Anaktuvuk, however, the curved front continues in a northeasterly and finally north-northeasterly direction, so that in about latitude 70° and longitude 147° it reaches a point within 35 miles of the coast, where it merges with the Franklin Mountains, one of the northern groups previously noted. From this point eastward to Mackenzie River the northern edge of the mountains continues near the coast.

Along the one hundred and fifty-second meridian the range is somewhat higher in the northern than in the southern part, and contains two distinct orographic axes, the surface of the northern having an elevation of a little more than 6,000 feet, and that of the southern somewhat more than 5,000 feet. Between these axes there is a slight depression, where the surface has apparently been somewhat more rapidly reduced by erosion in soft rocks. This is notably true on the west side of John River, somewhat north of the middle of the range, where in the region of the sixty-eighth parallel and the one hundred and fifty-third meridian the country between the head of Hunt Fork, which flows southeastward into John River, and the head of the Colville on the northwest, probably does not exceed 5,000 feet in elevation.

The topography of the range varies, depending on the character and structure of the rock formations. That of the Fickett series, composed of phyllites, slates, quartzites, and conglomerates, is characterized by sharper crests and peaks than the limestone areas, whose ridges, being broader and more rounded, are often studded by knobs and bordered by steep cliffs, with extensive slopes of heavy talus at their foot.

Though marked cliffs and precipices occur, the side slopes of the valleys, as shown in Pl. VI, *A*, can generally be ascended without difficulty. They are moss covered to within about 2,000 feet of the top of the mountains, where steeper slopes of barren rock and talus begin. Exceptions occur in the faulted Paleozoics in the northern side of the range, at the head of the Anaktuvuk, where some scarps rise abruptly to a height of several thousand feet above the valley.

ANCIENT PLATEAU FEATURE OF ENDICOTT MOUNTAINS.

Where best observed on this reconnaissance, principally on John and Anaktuvuk rivers, a view across the top of the range presents the general appearance of an ancient plateau or peneplain from which, by deep dissection, the mountains have been carved. The former surface of the plateau is evidenced by numerous closely crowded peaks, rising generally to an elevation of 6,000 feet, where they present an even sky line, as shown in Pl. VII, *A* and *B*. For this plateau feature of the range the name Endicott Plateau is proposed. About 4,000 feet below this level lie the floors of the main valleys, at an elevation of about 2,000 feet; and the open Anaktuvuk Pass, near the northern edge of the range, between John and Anaktuvuk rivers, is at an altitude of scarcely 2,500 feet.

Since for geologic purposes the accompanying geologic section (see section on Pl. III) is confined to the line of traverse along the valleys, where the elevation has been much reduced by erosion, the profile of the section does not express the plateau character of the range. This feature is probably best shown in the illustrations forming Pl. VII, which are reproduced from photographs taken on the upper part of John River, near the top of the range, at an elevation of about 6,000 feet.

It seems to the writer not improbable that, as our knowledge of the physical geography of Alaska becomes more complete, it will be found that the Endicott Plateau, including its extension to the east, possibly beyond the Davidson Mountains, may be correlated with the Chugach Plateau, a similarly dissected plateau surface, which is observed in the westward continuation of the St. Elias Range, at an elevation of about 6,000 feet.[a]

The interstream areas, which in general rise to the surface of the Endicott Plateau, are rarely flat topped, but consist of a network of peaks connected by irregular and often sharp-crested ridges. Only occasionally does an isolated peak rise a little above the general level of the plateau. None that could be observed are monadnocks.

The relation of the Endicott Plateau to the supposed Yukon and Koyukuk plateau features, to be considered later, is diagrammatically illustrated in fig. 2 (p. 44). So far as known, no rocks younger than Lower Carboniferous have been found in the Endicott Plateau. But as it seems not improbable that Upper Carboniferous and possibly even Lower Mesozoic rocks may be present in the Fickett series, it does not seem safe to suggest for the plateau an age earlier than Mesozoic. It seems undoubtedly older than the supposed Yukon Plateau, which in turn is considerably older than the Koyukuk Plateau, as the latter lies at a much lower level and is composed of rocks which are in part Cretaceous, and some possibly younger.

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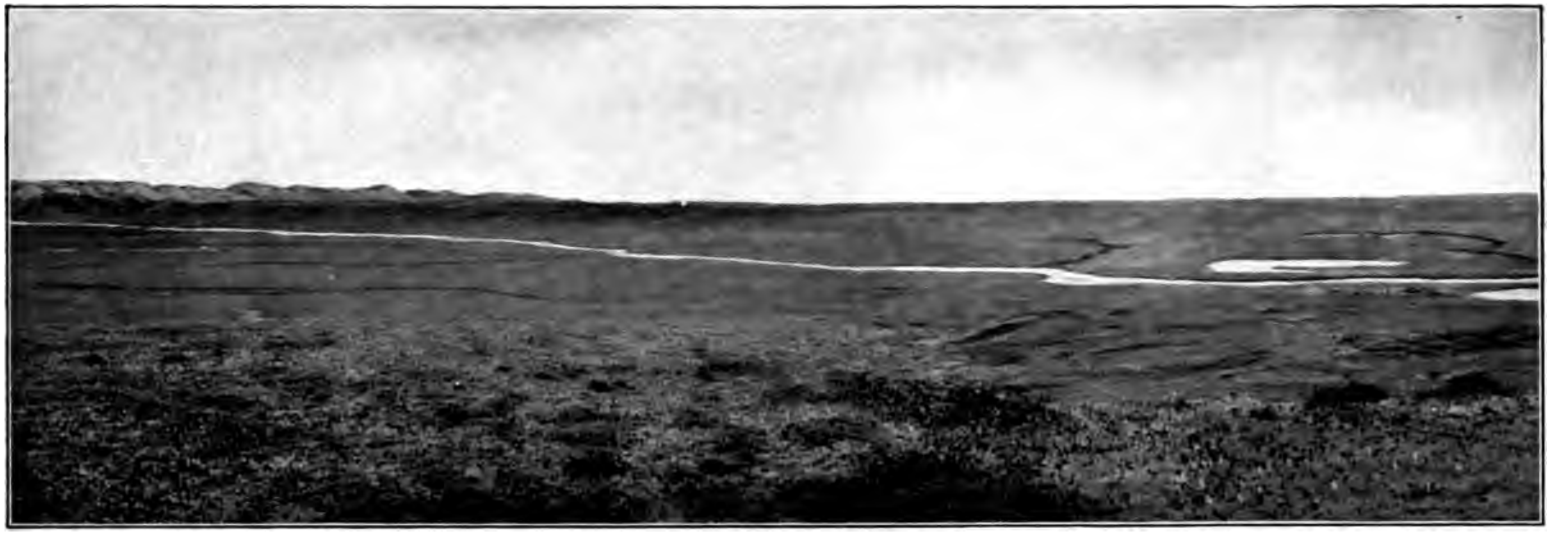
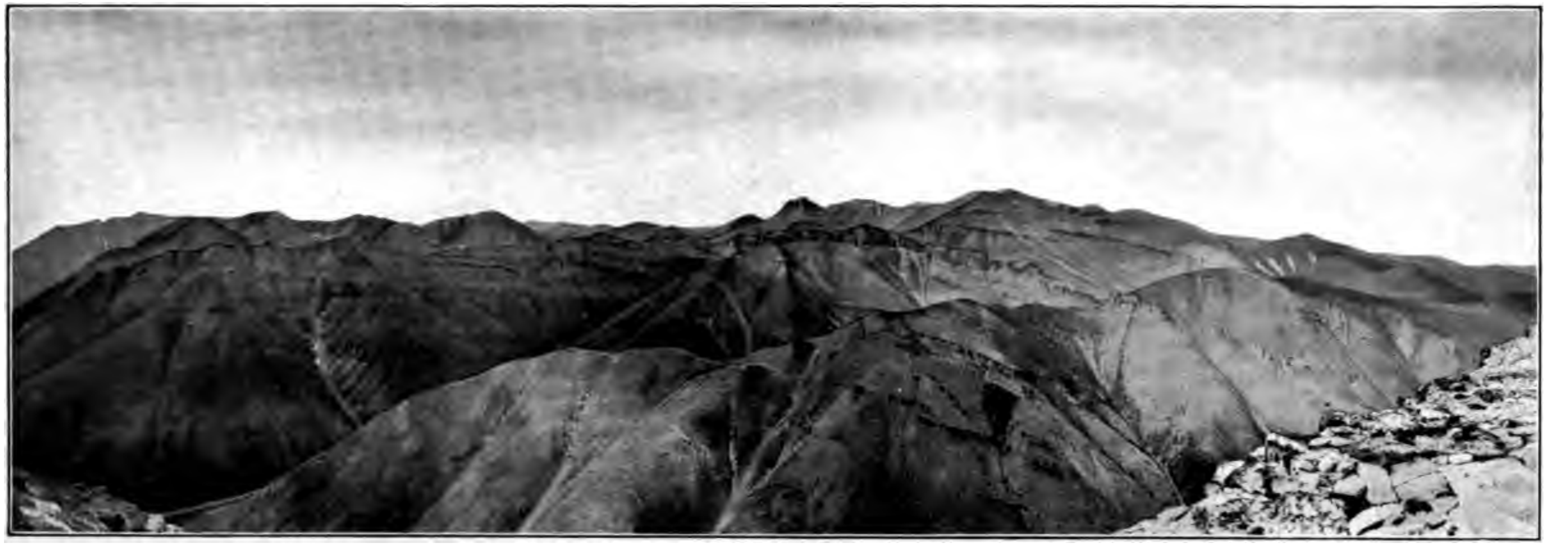
[a] Schrader, F. C., and Spencer, A. C., Geology and Mineral Resources of a Portion of the Copper River District, Alaska; a special publication of the U. S. Geol. Survey, 1901.

See also Schrader, F. C., A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 375.



A. INLAND EDGE OF ANAKTUVUK PLATEAU AND NORTH BASE OF ENDICOTT MOUNTAINS.
From surface of the plateau at 2,200 feet; looking southwest.



B. LISBURNE LIMESTONE AND FICKETT SERIES IN ENDICOTT MOUNTAINS AT HEAD OF JOHN RIVER.
From an altitude of 6,000 feet; looking west. Fickett series is in left background.

Since the Yukon Plateau, as to whose age there is slight difference of opinion, has been shown by Dawson,[a] Spurr,[b] and other writers to be due to Eocene or early Neocene erosion, if the present writer is correct in his supposition concerning the representation of this plateau feature in this northern field, the interrelations of the several features here make it obvious that the Endicott Plateau, which is certainly post-Lower Carboniferous, must be at least pre-Neocene and is probably considerably older, and that the Koyukuk Plateau is at least post-Eocene and possibly considerably younger.

DRAINAGE.

In the portion of the range crossed by the Survey party the drainage is principally southward into the Koyukuk. The master stream is John River, which rises near the northern edge of the range. The main drainage ways are therefore transverse, extending across the strike and trend of the rocks, as well as across the trend of the range. The small tributaries, being nearly always controlled by rock structure, flow in general along the strike and enter the master stream at right angles, producing a rectangular drainage system.

Though John River Valley is intramontane and contains some canyons, it is broad and in general open. A portion of it, near the middle part of the range, seems to lie in a syncline in the Fickett series, trending a little east of south. The valley probably averages about 1½ miles in width, from base to base of the mountains. Portions, however, are much wider and contain flats, through which the river freely describes great bends from side to side. The present stream channel has apparently been sunk into several older valley floors, as is shown by the bed-rock benches along the sides of the valley. Of these benches the most pronounced occur at heights of 1,700 feet, 600 feet, and about 100 feet above the present stream, and seem to mark stages of comparative rest in the progress of orographic uplift. It is probable that the 600-foot bench may be correlated with the benching noted on the Koyukuk, in the region of Red Mountain.[c]

At the head of John River, benches sloping northward against the present drainage seem to denote that a considerable area lying at the head of this stream formerly drained northward, through the Anaktuvuk and the Colville, into the Arctic Ocean, instead of southward, through the Koyukuk and the Yukon, to Bering Sea, as at present.

The bed-rock benching and the topography of the lower side slopes of the valley are frequently found to have been materially modified by ice action, which has eroded the rocks and brought down deposits of gravel and drift, as shown in Pl. VI, *B*. Such deposits, however, rarely attain a thickness of more than 100 feet.

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[a] Dawson, G. M., The physiographical geology of the Rocky Mountain region in Canada: Trans. Royal Soc. Canada, vol. 3, 1890, sec. 4, pp. 1-74.

[b] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 257-265.

[c] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 468.

The John River system, just described, is believed to be a fair type of the other adjacent drainage systems of the mountains, such as Hokotena River or Wild Creek and North Fork, which trend parallel to it and also flow south into the Koyukuk.

KOYUKUK PROVINCE.

GENERAL FEATURES.

This province, extending from the southern base of the mountains 120 miles southwestward to the limit of the map at the sixty-sixth parallel, lies mainly in the northwestern part of the large basin of the Koyukuk, which forms the northwestern part of the Yukon Basin.[a] It consists mainly of a rolling or hilly country of known and supposed Mesozoic rocks, whose hills rise to elevations of from 1,000 to 3,000 feet, while the main valley floors lie at approximately 600 feet.

The general accordance in height of the hills and ridges of this province at two different levels strongly suggests that the present topography has been carved from two former plateau features (see fig. 2). Though, for need of further investigation, this question can not be discussed in detail in this place, it may be noted that of these two features the lower level, at about 1,200 feet, is relatively distinct and well marked, and represents the general elevation of the land mass over the larger part of this portion of the Koyukuk Basin, as may be seen on the map (Pl. II). For it the name Koyukuk Plateau is suggested.

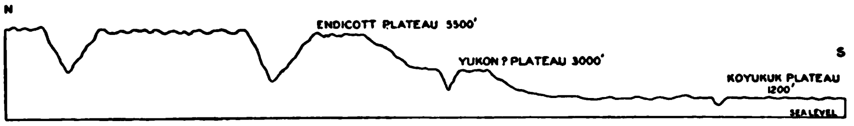

FIG. 2.—Diagrammatic profile showing relations of Endicott, Yukon, and Koyukuk plateaus.

The higher level, which also suggests a former plateau now dissected and largely removed by erosion, lies at about 3,000 feet, but it is indefinite. Its best expression occurs along the base of the mountains, where portions of nearly flat-topped ridges, rising gently northward, soon merge into the foothills of the mountains, while to the south they become lost in irregular ridges and hills, descending to the lower or Koyukuk Plateau. This higher level, where formerly observed, at an elevation of from 2,500 to 3,000 feet, to the east, on Chandlar and upper Koyukuk rivers, near the sixty-seventh parallel, was supposed to represent the Yukon Plateau,[b] but

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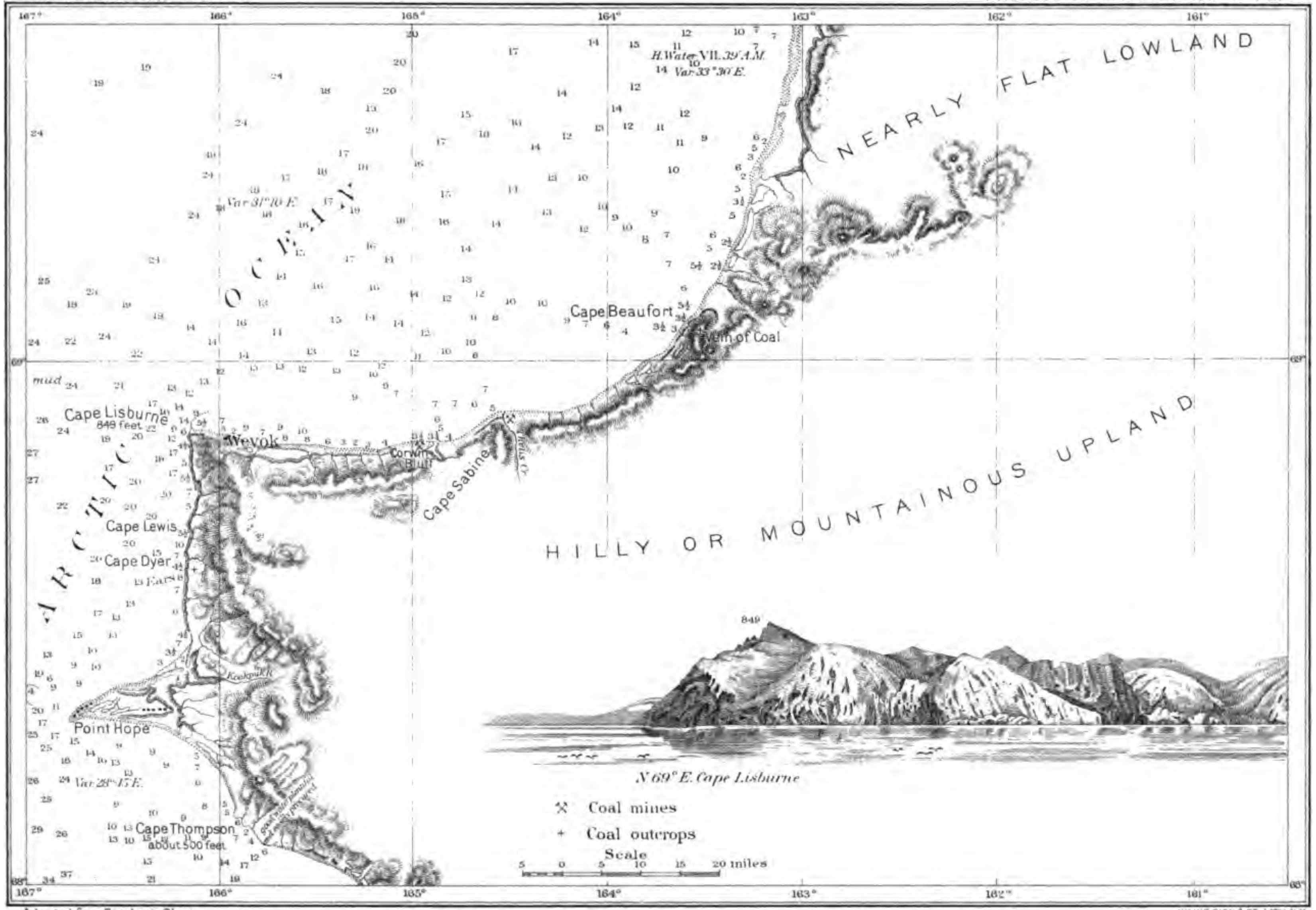
[a] For a more complete description of the Koyukuk Basin the reader is referred to Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 467. See, also, Recent work of the United States Geological Survey: Bull. Am. Geog. Soc., vol. 34, No. 1, Feb., 1902.

[b] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 99.



Adapted from Beecheys Chart

JULIUS BIEN & CO. LITH. N.Y.

SKETCH MAP OF CAPE LISBURNE REGION
SHOWING COAST LINE AND LOCALITIES OF COAL DEPOSITS

owing to its feeble development to the northwest and to its remoteness from the known Yukon Plateau feature, the present work, though it yields supporting evidence, has not gone far toward confirming this supposition.

DRAINAGE.

The drainage of this province, which is separated from that of the Arctic slope by the above-described mountain range, is southwestward. The master stream is the Koyukuk, which flows into the Yukon. It is navigable for some distance above Bettles, to near the sixty-seventh parallel. Next in size are John and Alatna rivers, tributaries to the Koyukuk from the north, and South Fork from the south, all of which at high water may be ascended by steamboat for 20 to 30 miles above their mouths. Other prominent tributaries are Hokotena River or Wild Creek and Alashuk River from the north and Kanuti River from the south.

All the above streams, as shown on the map, meander over their broad, flat valley floors, which vary from 1 to 10 or more miles in width. On the lower and middle portion of the Koyukuk the flats attain a very much greater width, being, in a measure, comparable with the Yukon Flats. To this portion the name Koyukuk Flats[a] has been applied.

ARCTIC SLOPE PROVINCE.

This province, beginning at the north base of the Endicott Mountains, in latitude 68° 25′, extends 160 miles northward to the Arctic coast. From the Anaktuvuk and Colville it appears to extend eastward to the foot of the mountains, 70 to 80 miles distant, while on the west it is inferred to probably extend to the Arctic coast, between Point Barrow and Cape Lisburne, a distance of about 400 miles. It is mainly with the eastern portion of the province that we shall here have to deal. This portion embraces almost the whole of the Colville Basin, and consists primarily of two distinct features, plateau and coastal plain. For the former feature the name Anaktuvuk Plateau is proposed.

ANAKTUVUK PLATEAU.

Beginning at the north base of the Endicott Range, at an elevation of 2,500 feet, as shown on the left in Pl. IV, *A*, this gently rolling plateau or plains country, composed of Mesozoic rocks, extends with gentle slope northward for a distance of 80 miles, to latitude 69° 25′, where, at an elevation of 800 feet, begins the nearly flat coastal plain next to be described. In the Anaktuvuk Valley a still more gentle aspect is given to the topography of the Mesozoic rocks by the glacial drift.

The most prominent features of this plateau are a few low, broad ridges, which lie parallel to or concentric with the curved front of the mountain range, and the shallow drainage valleys (see Pl. IV, *A*), trending north and south. These ridges present the concavity of their curve to the north, and, as suggested, appear to owe their origin to a part of the same uplift that formed the more abrupt front of the main range. They seem to be persistent features between the Colville and the head of Chipp (Ikpikpuk) River, where they trend a little north of west. Farther west they presumably merge into the Meade River Mountains, at the head of Meade River, in latitude 69° 20′, and probably continue still farther westward to the Arctic Ocean, where much the same type of topography, also cut in Mesozoic rocks, appears in the region north of Cape Beaufort.

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[a] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 468.

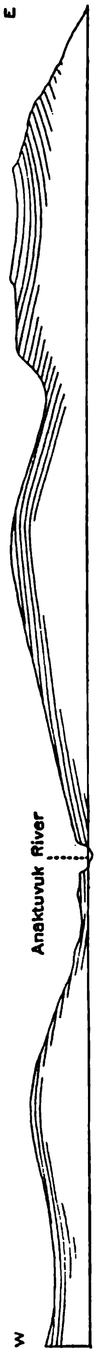


FIG. 3.—Sketch profile showing structure in Anaktuvuk series on Anaktuvuk River 10 miles above Willow Creek.

Where traversed by the Survey party, the most pronounced of these ridges occurs about 20 miles north of the mountains. It is low, broad, and somewhat rounded. Its highest points rise only 500 to 600 feet above the general plateau level, or about 1,200 feet above the bed of Anaktuvuk River. A sectional profile of this ridge, sketched from a point a few miles above it, on the Anaktuvuk, is presented in fig. 3.

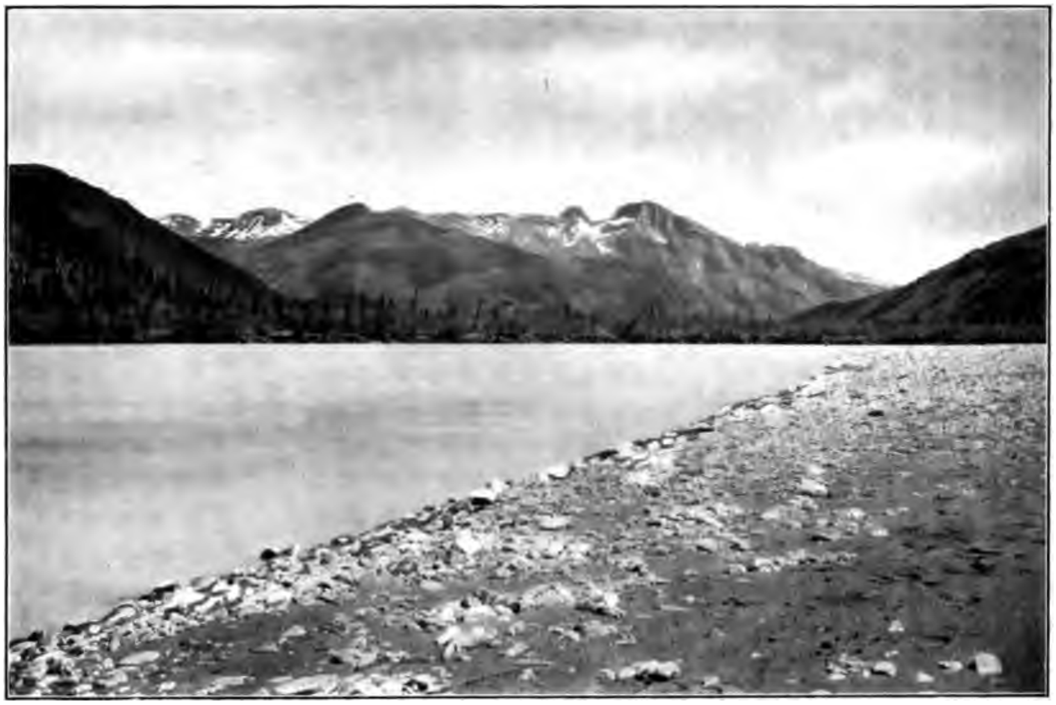
ARCTIC COASTAL PLAIN.

In latitude approximately 69° 25′, at a distance of 80 miles from the mountains, and at an elevation of about 800 feet, the northern edge of the above-described Anaktuvuk Plateau gives way to a nearly flat tundra country or coastal plain, which from this point extends about 80 miles northward to the Arctic coast, and descends in this distance practically to sea level, with slope so gentle as to be inappreciable to the naked eye. For this feature, by reason of its geographic position, the name Arctic Coastal Plain is here proposed. This plain is practically constructional. The flat surface of its large interstream areas is dotted here and there by extremely shallow ponds and lakelets, which in most instances are without outlet and present no suggestion of the development of any system of drainage. Along the west side of the Colville the eroded edge of this part of the plain forms continuous steep bluffs, which gradually decrease in height northward, from 200 feet at the mouth of the Anaktuvuk to about 80 feet at Ocean Point, 40 miles distant. The few rivers that traverse the plain flow with considerable velocity in its inland portion, but toward the coast they become sluggish.

DRAINAGE.

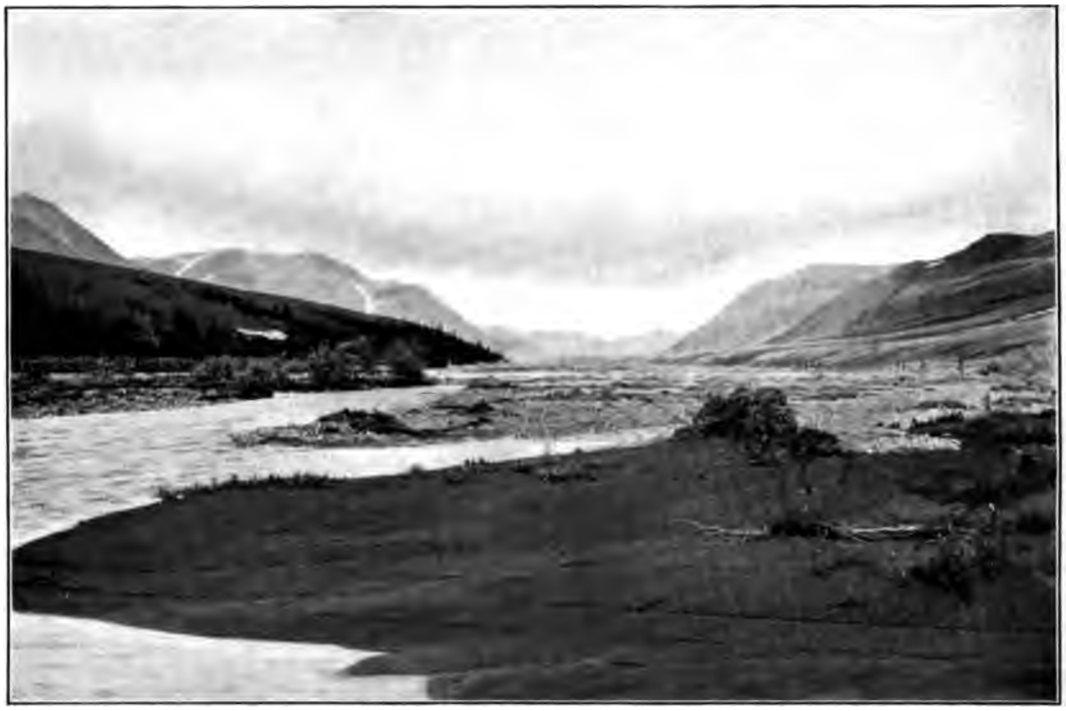
COLVILLE RIVER.

The drainage of this Arctic slope province is essentially northward, into the Arctic Ocean. The master stream is Colville River. The Colville has a drainage basin of about 30,000 square miles. It rises in the



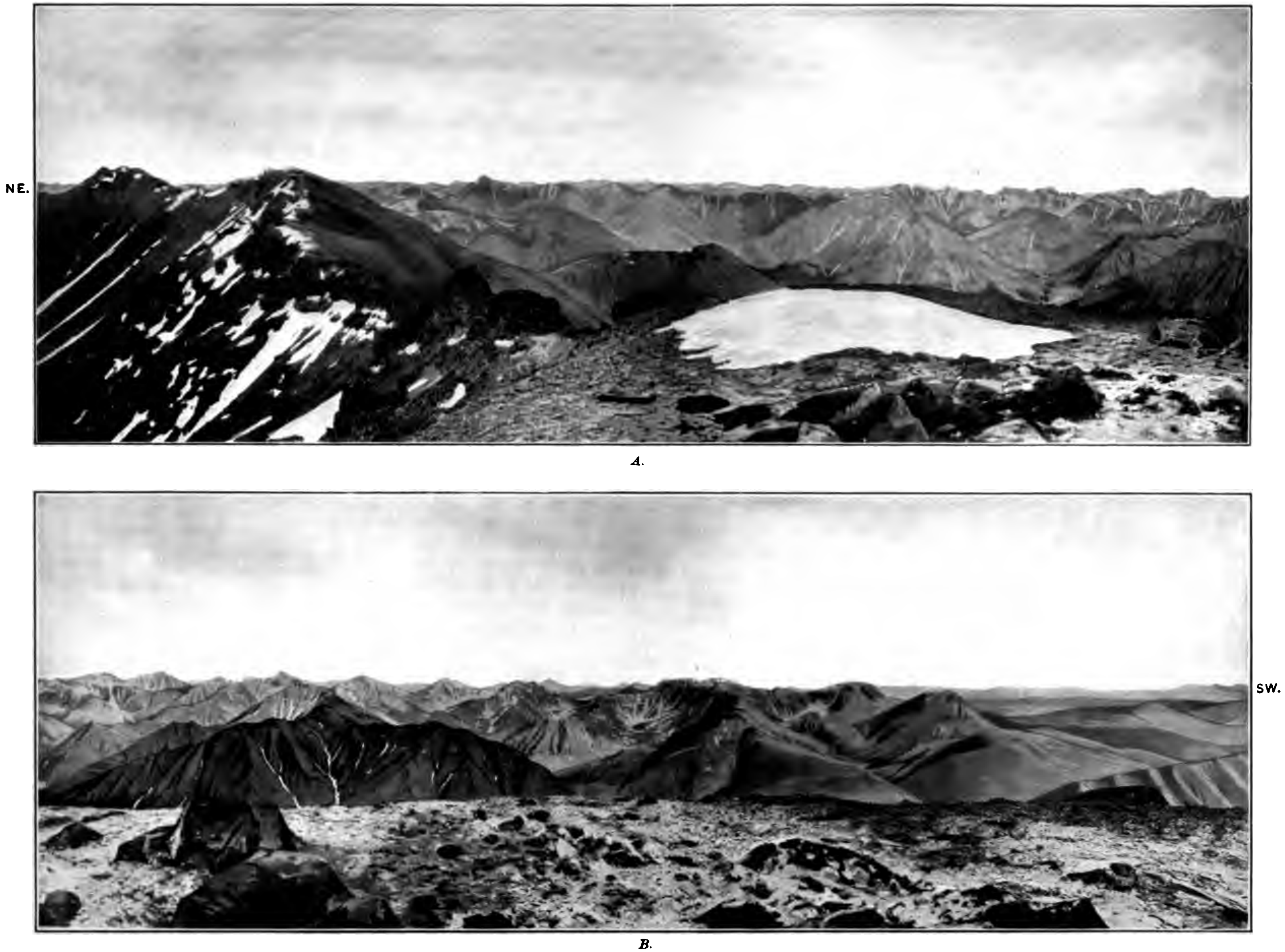
A. TOPOGRAPHY OF JOHN RIVER VALLEY IN ENDICOTT MOUNTAINS.

From near south edge of Fickett series; looking S. 60° E., into Skagit formation.



B. GLACIATED SIDE SLOPES OF JOHN RIVER VALLEY IN ENDICOTT MOUNTAINS.

Looking N. 15° E.



BISECTED VIEW OF ENDICOTT PLATEAU AND ENDICOTT MOUNTAINS CARVED FROM IT, PRINCIPALLY IN FICKETT SERIES.

From Fork Peak, at 6,000 feet, near head of John River. *A*, Looking east; *B*, looking south.

northern part of the Endicott Mountains, near the sixty-eighth parallel and the one hundred and fifty-third meridian, whence it soon makes a large detour to the west and back, and then, in flowing northward to the ocean, traverses both the Anaktuvuk Plateau and the coastal plain. Practically all its tributaries of any importance are received from the right, or southeast. The chief of these—the Ninuluk, Anaktuvuk, and Itvelik—head in the mountains.

In the inland part of the coastal plain, at the mouth of the Anaktuvuk, as shown by continuous bluffs, the Colville has sunk its bed to a depth of 200 feet (see Pl. VIII), and at Ocean Point, 40 miles farther north, where it permanently leaves the bluffs, to a depth of 80 feet below the surface of the plain. In this downcutting, from a point above the mouth of the Anaktuvuk to the coast, the Colville has migrated laterally westward, into the terranes composing the plain, to such an extent that, while its left or western shore is for the most part lined by steep-faced bluffs, rising from 80 to 200 feet above the stream to the level of the plain, into which it is still cutting, on the right or east it is bordered by an expansive waste of low abandoned flats, laid waste by the river, for which the name Colville Flats is proposed.

These flats occupy a triangular area of probably 2,000 square miles, extending from the mouth of the Anaktuvuk as the apex northeastward to the coast, where, including the Colville delta, they attain a maximum width of probably 50 or 60 miles. They are dotted by numerous shallow ponds and lakelets. The monotony of their almost dead level is occasionally relieved by low mounds of gravel, rising 10 to 40 feet above the surface. In fact, from near the mouth of the Anaktuvuk the Colville seems formerly to have flowed more directly northeastward through the area now occupied by the flats and entered the ocean through Gwydyr Bay, from 30 to 40 miles east of its present delta, if not Prudhoe Bay, still farther eastward, at the base of Return Reef, as shown by the broken lines on the map forming Pl. III.

At the head of the Colville delta, where the edges of these flats form the stream banks, their surface lies about 10 feet above the river. Here they are composed chiefly of dark mud, muck, and ground ice, while at certain localities farther inland the banks give way to stretches of gravel beach sloping gently to the water's edge.

The Colville delta at present has a radius of about 15 miles and a width across the front of about 20 miles. It is composed of low islands, which coastward gradually pass into marshes, mud flats, bars, and expansive shallows, which are continuous with the very gradually deepening sea floor. Near the head of the delta sand dunes have been formed on some of the islands to a height of 60 or more feet. As the "Pelly Mountains" of Dease and Simpson, represented on their map to the west of the Colville delta, do not exist, it seems probable that the features which these men mistook for mountains were merely low sand dunes, similar to those above referred to. This view is strengthened by the fact that under certain conditions of light along the coast low objects become, by refraction, enormously exaggerated in vertical scale.

Colville River has formerly been described as having four mouths, but it probably has five or six. The westernmost is said to be shallow, but the second from the west is navigable and is used by the natives in ascending and descending the river on the west. Whether any of these channels will admit river steamboats was not learned. If so, it must be the right or most easterly channel, which seems to be the main one. Once across the delta, judging from its gradient and volume, the river can probably be ascended by steamboat for a distance of 150 or more miles above its mouth. McClure, in crossing Harrison Bay in 1850, found the freshening influence of the Colville to extend 12 to 14 miles seaward, the surface of the water being of a dirty mud color and scarcely salt.

ANAKTUVUK RIVER.

Next to the Colville, the principal stream of this province is Anaktuvuk River, the large southeast tributary of the Colville, which, rising in the northern part of the mountains, flows almost directly northward across the Anaktuvuk Plateau and joins the Colville at the inland edge of the coastal plain. At about 30 miles from the mountains the Anaktuvuk is joined on the east by Willow Creek, a stream equal to itself in size.

Above Willow Creek, owing to the swiftness of the current and frequent riffles formed by large bowlders that beset the bed of the stream, the Anaktuvuk can hardly be regarded as navigable at ordinary water for canoe or rowboat. In the upper section of the river, the valley, as shown in Pl. IV, *A*, is shallow and open, with no bluffs or banks to speak of. The tundra extends almost to the water's edge.

Below Willow Creek the floor of the valley consists of a gravel- or bowlder-covered flat, a mile or more in width, along the edges of which the gentle, moss-covered side slopes are occasionally interrupted by low bluffs rising from 20 to 100 feet above the river. Willow Creek and Nanushuk River both seem to head in the mountains to the southeast of the edge of the plateau, while Tuluga River, on the west, apparently takes its rise on the plateau, near its middle part.

COAST LINE.

From Colville River to Point Barrow.—The northern Arctic coast of Alaska, from the mouth of the Mackenzie to Point Barrow, trends a little north of west. It is low and flat, the actual shore line being formed by a low shelving beach (Pl. IX, *A*), whose seaward extension forms the shallow sea floor. From east of the Colville westward to Point Barrow the surface of the tundra often descends to or within a few feet of tide level, so that the same gentle slope seems to be continued in the very

A

C

BISECTED VIEW OF COLVILLE RIVER B

A and *B*, Lookii

B

D.

' COASTAL PLAIN OF COLVILLE SERIES.

ooking northwest.

gradually deepening sea floor. The greatest height of the bluffs is about 30 feet. The drainage ways are consequently broad and very shallow.

The coast line is comparatively regular, though not nearly so uniform as represented by the early explorers Dease and Simpson. It is more or less broadly sinuous or wavy, its first striking uniformity being broken by occasional lagoons, shallow embayments, and inlets; but in comparison with the coast of southern Alaska, for example, in can not be called indented. Some of the embayments mark the mouths of rivers, but most of the larger ones seem to occur independent of inland drainage. The deepest, and perhaps the only one to which the term indentation will strictly apply, is Dease Inlet, at the head of which is situated Admiralty Bay, which receives the Chipp (Ikpikpuk) River. The principal streams entering the sea between the Colville and Point Barrow are Garry, Smith, Sinclair, Chipp (Ikpikpuk), and Meade rivers. These rivers, however, could not all be visited by the party in its rapid progress along the coast. So far as known, they in general have wide mud-flat deltas, much the same as the Colville, which pass seaward into shallows, merging with the shallow coastal shelf of the sea.

It is judged that the coastal shelf extends far offshore, with a slope probably even less than that of the nearly level subaerial coastal plain. Captain McClure found the soundings so exceedingly regular that during the foggiest weather the vessel could stand inshore with the most perfect confidence in 3½ fathoms of water, and the *Investigator* is reported to have passed the mouth of the Colville 40 miles out to sea in 3½ fathoms. The range of tides on this portion of the Arctic coast is very small, being only 2 or 3 feet.

Point Barrow, the northern extremity of this low coast and of the American continent, is a low spit of gravel and sand, projecting to the northeast, in latitude 71° 23′, longitude 156° 40′. It is 4 miles in length and about one-fourth mile in width, but expands at the end, where it rises to a height of 16 feet and sends out a long, narrow ridge, which extends east-southeastward for a distance of more than 2 miles. This ridge finally gives way to a line of sandy islets, inclosing a shallow body of water of considerable extent, named Elson Bay, after the discoverer of Point Barrow.

From Point Barrow to Cape Lisburne and beyond.—The trend of the coast line changes from northwest to southwest at Point Barrow and thence extends about 300 miles southwestward to Cape Lisburne. It continues comparatively straight and regular, but it is not so low as on the north. It soon loses the almost featureless edge which is characteristic of the flat coastal plain on the north, and gradually comes to exhibit low, but seldom rock-faced, bluffs, rising 30 or 40, rarely 70, feet above tide. Back from the shore a very gently rolling surface rises very gradually toward the interior, but no highlands or mountains can be seen. Seaward the bluffs overlook immense stretches of brackish lagoons, from one to several miles in width, which rather persistently line the coast. These lagoons are screened from the force of the open sea by broad wave-built barrier reefs and beaches of sand and gravel, through which occasional narrow channels, cut by the ebb and flow of the tide, connect with the outer water. On portions of the coast not thus protected, during a northwest gale the mouths of the smaller valleys become entirely clogged and the streams themselves are then dammed back by the broad beach barriers thrown up by the violent surf. In the rear of these barriers the lower reaches of the valleys then become temporarily converted into broad lakelets, whose surface may rise 5 or 6 feet above normal tide level; but with the abatement of the storm a new drainage channel is opened through the beach and the lake disappears.

Near Cape Beaufort, latitude 69° 15′, the above-described low topographic relief gives way to a range of hills or low, rolling mountains, which, sweeping a little south of west, appear at the coast with an elevation of 800 to 1,000 feet. They are supposed by the writer to represent the westward continuation of the Meade River Mountains, already referred to. Farther southwest they seem to merge into the somewhat more pronounced and rugged mountains of Cape Lisburne, which, as noted, are supposed to represent the westward continuation of the northern axis of the Endicott Range, noted at the head of the Anaktuvuk, in longitude 152°.

Here these mountains, as noted, terminate at the coast in abrupt sea cliffs, forming the bold promontory of Cape Lisburne, which rises to a height of 850 feet above tide. From Cape Lisburne the mountains, with decreased altitudes, continue southwestward in several successive parallel ridges, trending at about right angles to the coast. The shore line, however, is here less abrupt, as shown in fig. 1 (p. 40).

About 30 miles south of Cape Lisburne the shore extends out nearly 15 miles to the west in an immense tongue of low, sandy land, known as Point Hope, which is backed by bluffs at its inland end.

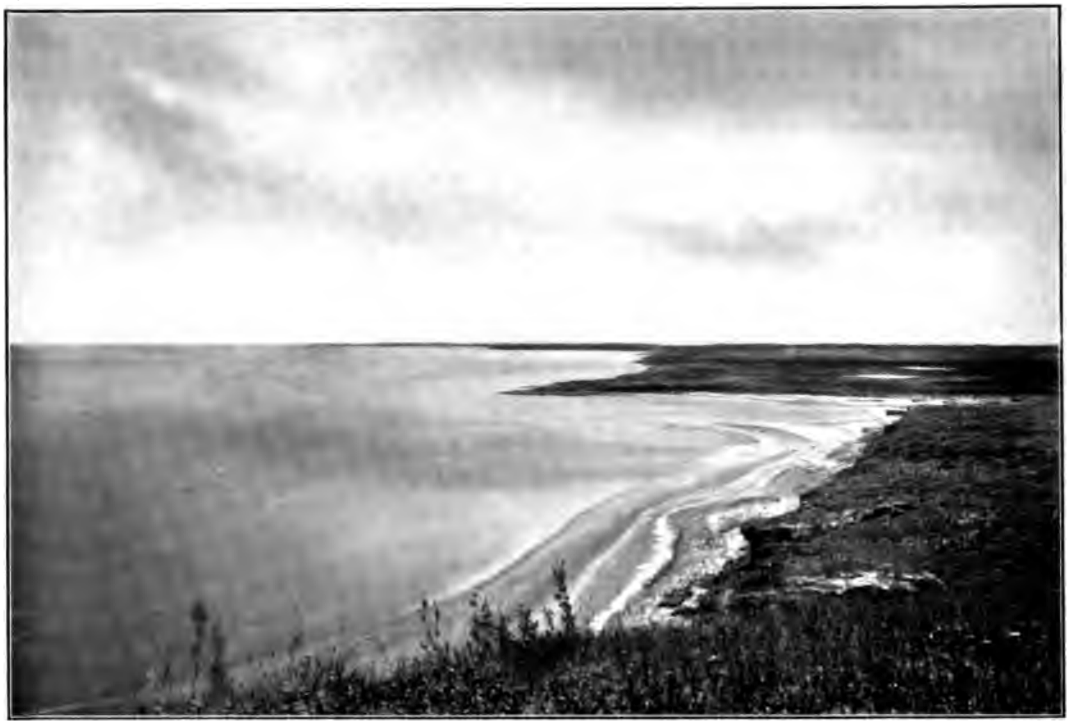
From Point Hope southeastward to Cape Krusenstern, at the entrance to Kotzebue Sound, the coast is reported to be low and somewhat rocky, with intervals of lagoons and wave-built barrier reefs, somewhat resembling those already described; but in latitude 67° 35′, opposite the great bend of the Noatak, low mountains, known as the Mulgrave Hills, again approach the coast.

The streams entering the coast on the northwest are nearly all short. The principal, beginning at the north, are Kee, Kukpowruk, Pitmegea, and Kukpuk rivers.

GEOLOGY.

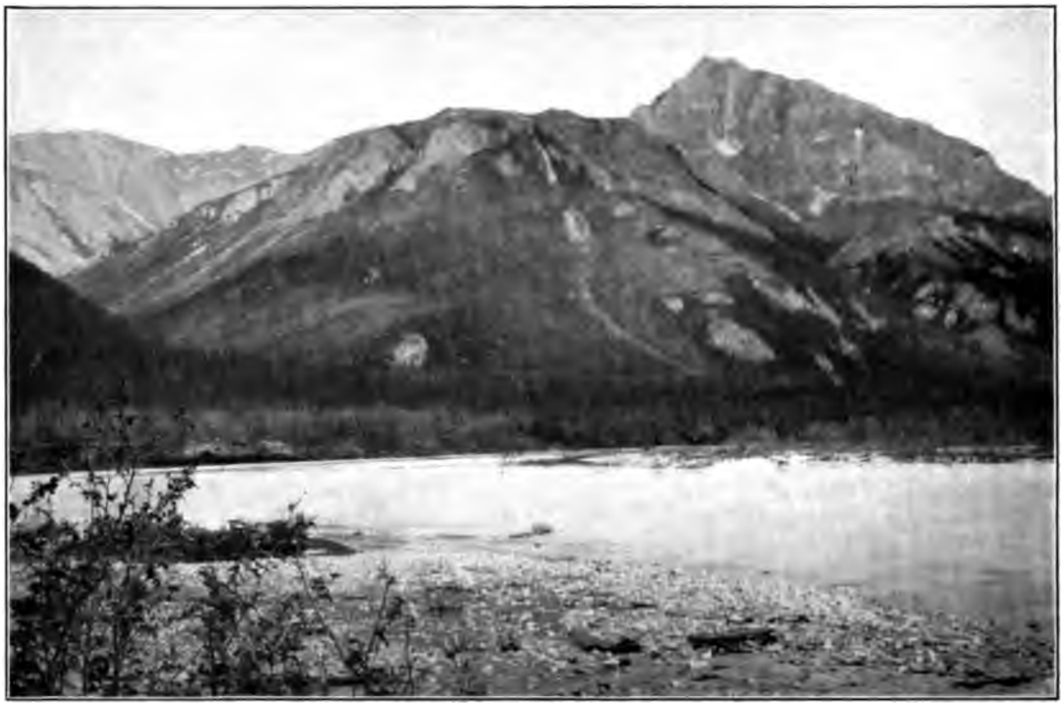
GEOLOGIC MAP AND SECTIONS.

The results of the very incomplete observations concerning the distribution of the geologic formations here treated of are represented on the accompanying geologic map (Pl. III), the colored portion of which, comprising an area of about 27,000 square miles, lies mainly between the one hundred and fiftieth and one



A. ARCTIC COAST AND EDGE OF MOSS-COVERED ARCTIC COASTAL PLAIN.

From west of Colville River; looking S. 45° E.



B. SKAGIT LIMESTONE ON JOHN RIVER IN ENDICOTT MOUNTAINS.

Looking S. 65° E.

hundred and fifty-fifth degrees of longitude. As the line of traverse extends in a north-south direction across the trend of the terranes, which has been found to be relatively constant, especially in the mountains, the boundaries delimiting the various formations on the north and on the south, along the line of the section, are approximately correct and in some instances are well defined. In an east-west direction some liberties have been taken in making such broad generalizations as seemed permissible from the regularity of the terranes in the mountains and their relations and lithologic resemblance to those previously mapped to the east.

The boundaries of the post-Paleozoic formations of the Arctic slope, approximately determined on paleontologic and lithologic evidence along the route of traverse, have been extended eastward and westward on topographic evidence and on observations and collections made by the writer in returning southward along the coast from Point Barrow to Cape Lisburne.

At the north base of the mountains, where the profile, descending from the mountains, passes from the upturned Devonian onto Pleistocene till, which farther north is found resting on Lower Cretaceous, a belt several miles wide has been left blank, in view of the possible occurrence of Carboniferous and Lower Mesozoic rocks between the Devonian and the Cretaceous; and similar contact gaps have been left in other parts of the section. On topographic grounds, however, it seems probable that the Mesozoic and Carboniferous formations are absent at the above point on the Anaktuvuk, having been removed by erosion, and that the inland edge of the Lower Cretaceous or Jura-Cretaceous may rest directly on the Devonian, as indicated in fig. 4. Areas away from the route traversed, where the geology is unknown, are also left blank; while, on the other hand, general geologic information and the probable occurrence of certain formations are represented by notes printed in red. East of the geologically colored portion of the map the notes applying to the region lying north of the Arctic Circle are based on the work of the writer in a previous year,[a] while those to the south of the Circle, on the west, and along Alatna and Kowak rivers in the region of the sixty-seventh parallel are by Mr. W. C. Mendenhall, geologist in charge of the Kowak expedition, whose work[b] has just been published.

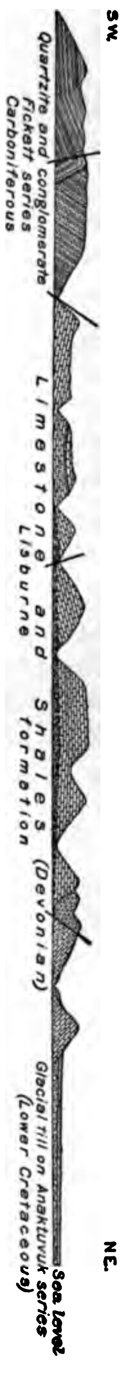

SW.
Quartzite and conglomerate
Fickett series
Carboniferous
Limestone and Shales (Devonian)
Lisburne formation
Glacial till on Anaktuvuk series
(Lower Cretaceous)
Sea Level
NE.

FIG. 4.—Geologic reconnaissance section on the Arctic divide west of Anaktuvuk Pass. Lower Cretaceous-Devonian contact is hypothetic.

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[a] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 448.

[b] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper U. S. Geol. Survey No. 10, 1902.

A profile and geologic section appearing on Pl. III, drawn on the same scale as the map, illustrate the structural features and relations of the various rock formations. It extends from the southern edge of the map at A (Pl. III) to the foot of the Colville delta and the Arctic coast at J. In order to show the structure in the Tertiary coastal plain and to represent the flats and delta near sea level at the north, the scale of the section has been vertically exaggerated 5:1 as compared with the horizontal scale, and in order to represent more accurately the relations of the rocks as actually observed the section follows the somewhat zigzag line of traverse. Where it traverses the rocks diagonally, as in the northern edge of the Fickett series, compensation has been made therefor by reducing the dips of the rocks in the section. As the line of traverse follows the valleys, where the topography has been reduced by erosion, the profile rarely rises to the normal height of the adjacent land mass. Consequently the peneplain feature of the Endicott Mountain summits is not expressed by the profile. From studies thus far made of the section it promises to be of far-reaching importance, not only in deciphering the geology of Alaska, but also in making correlations with Asiatic stratigraphy.

Near the northern edge of the range, as shown on the map, the section traverses the mountains to the east of the Anaktuvuk Valley, but as the rocks have here been disturbed by folding and faulting, a supplementary short profile section (fig. 4), showing the rocks as they appear on the west side of the valley, has been introduced. It extends from the Lower Carboniferous at Contact Creek on John River a distance of about 25 miles northeastward across the Devonian, along the north side of Anaktuvuk Pass, to the Cretaceous of the Anaktuvuk Plateau on the west of Anaktuvuk River. The base of this section represents approximately the elevation of the floor of the Anaktuvuk Valley and that of the pass, which is about 2,500 feet. The mountains rise to about 5,500 feet. Besides the faulting shown between the Devonian and the Lower Carboniferous on the south, and in the Devonian itself toward the north, the section supposes the Lower Cretaceous to be resting unconformably on the upturned and eroded Devonian.

OUTLINE OF GEOLOGIC HISTORY.

The rocks composing the section here considered, extending geographically from the sixty-sixth parallel to the Arctic coast, a distance of nearly 400 miles, comprise representatives of most of the geologic ages ranging from Silurian to Recent, as shown in the accompanying table.

TABLE OF GEOLOGIC FORMATIONS.

Sedimentary rocks.

Pleistocene		Recent stream gravels, dune sands, mud flats, silts, beach gravels, Gubik sand, ground ice, and glacial drift.
Tertiary (Colville series)	Pliocene	Nearly horizontally stratified, fine-grained calcareous silts.
	Oligocene	Sand, clay, shale, soft sandstone and limestone with lignites, hard ferruginous sandstone, and conglomerate.
Mesozoic	Upper Cretaceous (Nanushuk series).	Soft sandstone, limestone, shale, and coal.
	Cretaceous (?) (Bergman series).	Sandstone, slate, grit, conglomerate, and coal.
	Lower Cretaceous (Koyukuk series).	Impure limestone, sandstone, slate, and associated igneous rocks.
	Lower Cretaceous (Anaktuvuk series).	Principally impure sandstone or arkose, with some conglomerate or grit.
	Jura-Cretaceous (Corwin series).	Sandstone, impure limestone, shale, and bituminous coal.
Paleozoic	Lower Carboniferous (Fickett series).	Phyllites, slate, limestone, sandstone, quartzite, grit, and conglomerate.
	Devonian (Lisburne formation).	Limestone and shale.
	Silurian (probably) (Totsen series).	Mica-schists and quartz-mica-schists.
	Upper Silurian (Skajit formation).	Schistose and micaceous limestone.
	Pre-Devonian (probably) (Stuver series).	Conglomerate, quartzite, slate, and shale.

Igneous rocks.

Post-Silurian dike (?) rocks, associated with the Skajit formation.
Cretaceous and post-Cretaceous dike rocks, associated with the Koyukuk series.

The oldest rocks encountered in the field consist of several metamorphic series. They are principally of sedimentary origin, and have acquired their present character largely by processes of mountain building, which, broadly speaking, seem to have been in progress intermittently since Middle Paleozoic time, and are probably still going on.

These metamorphic rocks are exposed only in the mountainous portion of the field. The different series are here designated by the names Skajit, Totsen, Stuver, Lisburne, and Fickett. Though the Totsen series is mainly sedimentary, it includes also some greenstone-schists of igneous origin, which appear to be old basaltic flows, but may be intrusives.

With probably a single exception, igneous rocks were not observed with any of the other metamorphic series. This exception was on John River, near the middle of the Skajit formation, at a point about midway between camps of June 23 and June 24. Here, in the face of the upper part of a cliff which rises steeply to a height of 2,000 feet above the edge of the stream, as seen from the opposite side of the river, looking northeast, but which, owing to difficulty of access and lack of time was not visited, the limestone is cut by what appears to be two classes of dikes (but which may possibly be veins), one dark and the other light. These supposed dikes are thin, and they are younger than the schistosity of the country rock. The dark ones are the older, and cut the rock for the most part obliquely to the schistosity or bedding, which they slightly exceed in dip, the dip being to the north, at an angle of about 45°. The light dikes cut the rocks at nearly right angles to the dark dikes and dip south at an angle of about 80°, and seem to follow fault planes or fissures that were manifestly produced subsequent to the intrusion of the dark dikes.

The above division of the rocks is based largely on paleontologic evidence. But the Totsen series, in which no fossils were found, is assigned to a low place in the geologic scale by reason of its crystalline character or high degree of metamorphism and the known relatively low stratigraphic position in which similar rocks occur in adjacent regions. The Stuver series, in which likewise no fossils were found, is regarded as among the older rocks by reason of its field relations to the overlying Devonian.

After the deposition of the oldest Paleozoic sediments occurring in the present southern axis of the main range, this part of the region seems to have been uplifted and subjected to dynamic action and metamorphism, following which a portion of the field probably remained above sea during the whole or a part of the period in which the Devonian sediments were being laid down in the region now occupied by the northern axis. During this period of deposition, which possibly extended into early Mesozoic, the later Paleozoic sediments, including apparently the Carboniferous, seem to have been deposited unconformably against the older rocks of the southern axis. This period was followed by stress, uplift, and the exertion of mountain-building forces, resulting in folding, metamorphism, and deformation of the strata.

Then followed a long pause, during which the reduction of the land area by subaerial erosion nearly to sea level gave rise to the peneplain or formerly nearly level surface of the Endicott Plateau. This base-leveling was, in turn, followed by elevation of the region, whence upward movement seems to have continued more or less intermittently down to the present time. Uplift was accompanied by vigorous dissection of the plateau, from which the Endicott Mountains, as we find them to-day, seem manifestly to have been carved.

Contemporaneous with this uplift and dissection the sediments eroded from the range were borne to the sea and deposited as new terranes on both the north and the south side of the mountains. These later deposits range in age from Middle Mesozoic to recent. Though throughout this period the Endicott Plateau seems to have stood above the sea, the region was subjected to somewhat pronounced changes of level and disturbance, as is evidenced by deformation and unconformities extending from Middle Mesozoic to Pleistocene.

The later of these disturbances is that suggested by the vigorous cutting of the left or west bank of Colville River into high bluffs (Pl. VIII), while the east bank consists only of the edge of an expansive waste of low flats abandoned by the river in its lateral migration during its down cutting. This shifting or lateral migration of the river was evidently brought about by a tilt, which is apparently more than a local disturbance, for other examples indicate that there has been a general tilt throughout northern Alaska, which has caused and is still causing the larger rivers, notably the Yukon, the Porcupine, the Koyukuk, the Kowak, the Colville, and the Anaktuvuk, to cut their western banks.[a] This differential upward movement of the region probably extends eastward to the international boundary or farther, and, judging from the lateral migration of the Colville into the Pleistocene as well as the Tertiary and Mesozoic terranes, it took place, in part at least, in the Pleistocene, and is probably still in progress.

During Lower Cretaceous time, deposition on the south of the range, in what is now the Koyukuk Basin, was apparently accompanied by igneous extrusions and followed by intrusions, which latter continued into post-Cretaceous time,[b] while the range itself and the Arctic slope, so far as observed along the route of traverse, are relatively free from igneous rocks. It was supposed by the writer that the northeast-southwest trend of the Koyukuk Valley, from the Yukon to the sixty-eighth parallel, probably represented in a general way a line of weakness in the earth's crust, along which igneous phenomena are especially manifest. More recent work, however, along Kanuti and Kowak[c] rivers and on Kotzebue Sound, shows that the igneous rocks are distributed over a much wider area in this northern country than in that occupied by the Koyukuk Valley.

SEDIMENTARY ROCK FORMATIONS.

PALEOZOIC ROCKS.

STRUCTURE.

Beginning with apparently the oldest, the several formations or rock series will be briefly described. As the field is new and the investigations have not been detailed, the formation names introduced are proposed provisionally.

To afford a more comprehensive view of the relations of the several series and to avoid repetition in referring to them individually, it will be well to note at the outset some features of structure which are common to nearly all the Paleozoic rocks, and which apply to the range as a whole, namely, that the series all strike approximately east and west, parallel with the trend of the range. They are nearly all traversed by the dominant jointing of the range, which cuts the rocks in a direction about northeast-southwest, with dip nearly vertical or inclined steeply to the northwest, at angles of 75° to 80°. There are also usually one or more sets of secondary jointing or minor structure, trending in general northwest-southeast, sometimes approximately at right angles to the major jointing.

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[a] The fact that the Yukon in the lower part of its course is cutting its right or western bank has been noted by Dall. Russell, Spurr, and others.

[b] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 481.

[c] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper, U. S. Geol. Survey, No. 10, 1902, map, p. 30.

The above statement of the structures affecting the Paleozoics in the range applies also in a limited way to the upland Mesozoics on either side.

With the exception of the greenstone-schists occurring in the Totsen series, the Paleozoics of the range, as well as the younger formations of the Arctic slope, are all sedimentary, and, so far as observed, are relatively if not wholly free from association with igneous rocks of any kind.

SKAJIT[a] FORMATION (UPPER SILURIAN).

Character and occurrence.—The Endicott Range, as noted, has two distinct axes, of which the southern seems to be composed of the older rocks (see Pl. III), those of the Skajit formation and the Totsen series, the former playing the principal part.

The rocks of the Skajit formation (Pl. IX, *B*) consist of heavy-bedded crystalline limestone and mica-schist. Weathered surfaces, parallel with the bedding and planes of movement and crushing, present a silvery sheen, due to the presence of mica, while some layers grade wholly into mica-schist. On a fresh fracture surface the limestone is found to be highly crystalline, generally fine or medium grained, and of impure white or bluish-gray color, the latter apparently denoting the more dolomitic phases of the rock. It weathers to a dirty gray or light brown, sometimes tinged with red.

The formation occurs in the southern part of the Endicott Mountains, where, in latitude approximately 67° 30′, it occupies a belt that is from 15 to 20 miles wide, in which the mountains rise to an elevation of more than 5,500 feet above sea level, the rocks forming some of the highest peaks and most rugged topography of the southern axis of the range. Judging from the attitude or prevailing dip of the rocks and their extent measured across the strike, the formation probably has a thickness of at least 4,000 feet.

Structure.—The Skajit formation has a nearly east-west strike, parallel with the general direction of the mountains; but about 20 miles west of John River this trend changes to north of west. The structure in general indicates a broad anticlinorium whose middle part is occupied by a broad, shallow syncline. In general the dips are gentle, as shown in Pl. IX, *B* and Pl. X, *A*. The latter shows the

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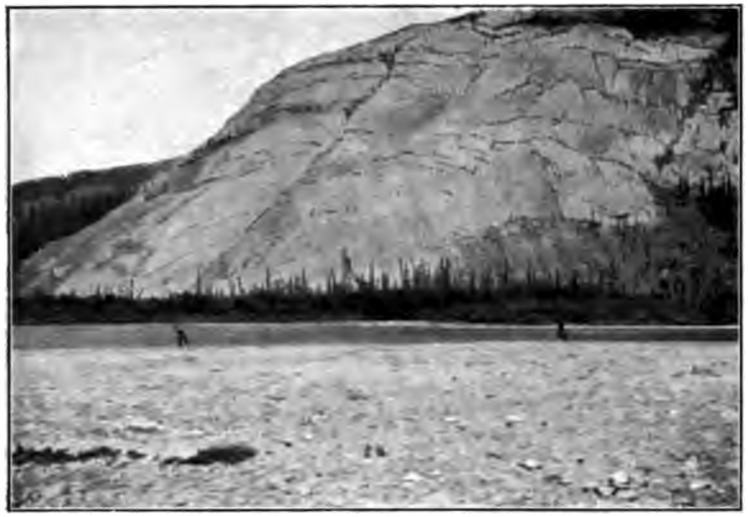
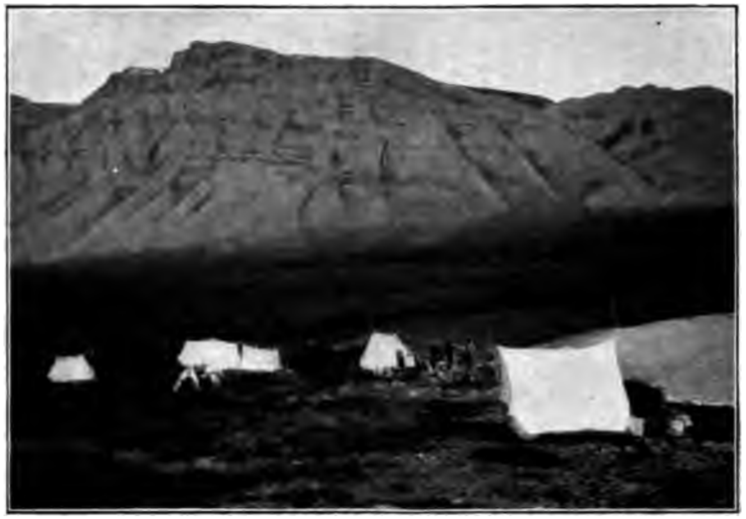
[a] The term Skajit is of native origin, and is taken from a group of rugged mountains occurring within the area of the formation to the east of John River.

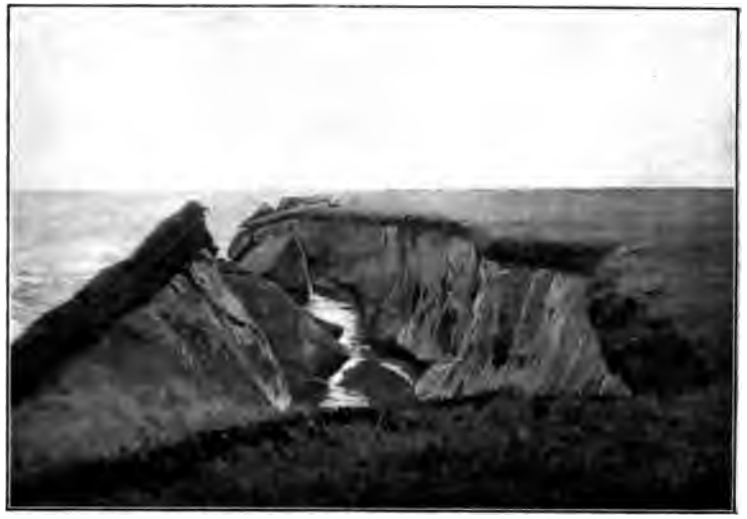


A. NORTH EDGE OF SKAGIT LIMESTONE, DIPPING NORTH, ON JOHN RIVER, IN ENDICOTT MOUNTAINS. LOOKING EAST.



B. LISBURNE LIMESTONE AND GROUND MORAINE, FROM CACHE LAKE NEAR ANAKTUVUK PASS, IN ENDICOTT MOUNTAINS. LOOKING NORTHWEST.

C. CAPE SABINE AND UNDULATING PLATEAU. LOOKING SOUTH.



D. CAPE HALKETT, SHOWING GROUND ICE TERRANE RISING 30 FEET ABOVE TIDE.

formation as it disappears to the north unconformably under the Fickett series. In some localities, however, the faulting and folding have been intense.

Like the other Paleozoic rocks of the range, the Skajit formation is cut diagonally by the dominant northeast-southwest jointing, which divides the rocks into nearly vertical sheets varying from less than 1 to more than 10 feet in thickness, and by the secondary jointing sometimes at nearly right angles to this direction.

The joint planes are usually nearly vertical or have a steep westerly dip, and are sometimes locally followed by veins or veinlets of calcite and some quartz, carrying occasionally a little galena or iron pyrites and copper. Prospectors report that galena, probably of economic value, occurs on Wild Creek, 25 miles east of our route, in a wide "ledge" in limestone probably belonging to the Skajit formation.

Cleavage was also noted in a few instances, but none so pronounced or so well developed as that observed in similar rocks in the area to the east, at the head of Chandlar River.

Age.—The Skajit formation, as seen in the geologic section, probably represents the oldest or next to the oldest rocks in the field. It is the principal formation forming the southern axis of the Endicott Range, of which it seems to be the lowest terrane exposed. It is unconformably below the Fickett series on the north, and apparently bears similar relation to the Totsen series on the south, where, as shown in the geologic section on Pl. III, the probable unconformity is indicated by the beds of the Totsen series lying at a steeper angle than those of the Skajit formation, as well as by an abrupt change in the character of the sediments along the zone of contact. Similarly, on the north, where the heavy-bedded limestone of the Skajit formation finally disappears with a northerly dip, it is met by the overlying slates and schists of the Fickett series dipping south (section on Pl. III and Pl. X, *A*).

Though the limestone, as noted, is much altered by metamorphism, it contains faunal remains, some of which were collected in place on John River. While most of these forms are too greatly altered for determination, a single specimen has been identified by Mr. Schuchert as "having the ventral valve of a brachipod of the order of *Meristina* and *Meristella*, and also resembling a transverse *Seminula*. This kind of shell indicates that the rock can not be older than Upper Silurian and not younger than Lower Carboniferous."

On this evidence, and because the rock is much more disturbed and metamorphosed than the limestone of the Lisburne formation, in which Devonian fossils have been found in the northern axis of the range, the Skajit formation is provisionally referred to the Upper Silurian. This, if the inference be correct, places it among the oldest known fossil-bearing formations of northern Alaska. Late Upper Silurian forms have been found in the Glacier Bay limestone in southeastern Alaska.[a] Ordovician fossils have been found by the Survey party on Seward Peninsula,[a] and Lower Silurian forms[b] were also found by Mr. A. J. Collier during the season of 1901 in the same region.

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[a] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902, pp. 19-20.

Silurian fossils are also reported to have been collected[c] by Buckland, Dall, and others at Cape Lisburne and the adjacent Cape Thompson, but, so far as known to the writer, no section or description of the rocks is given. In Dana's Manual of Geology it is stated that species of *Lithostrotion* have been found in the Arctic coast lands between Cape Lisburne and Kotzebue Sound. Lower Silurian fossils were collected by Mr. Schuchert on the northeast coast of the continent, in Baffin Land.

Correlation.—From the schistose, crystalline, and micaceous character of the Skajit formation and its resemblance to similar rocks of the Bettles series,[d] it is here provisionally correlated with the schistose phase of the Bettles series occurring at the head of Chandlar River, with which subsequent detailed work in the intervening region may connect it. It seems probable that the limestone reported by prospectors to occur in the gold placer district in the Koyukuk, between the Skajit formation on John River and that on the Chandlar, represents this connection. In an earlier report[e] the Bettles series was tentatively correlated with the Fortymile series of Spurr. If, however, the Skajit formation proves to be Upper Silurian and its correlation with the Bettles series is correct, the previous correlation of the Bettles limestone to the north of the Yukon with the pre-Silurian Fortymile series to the south, in the Fortymile district, may have to be abandoned.

TOTSEN SERIES[f] (SILURIAN).

Character and occurrence.—This series of rocks occupies a belt about 12 miles wide on John River. It lies south of the Skajit formation, upon which the Totsen rocks seem to rest unconformably, while they in turn are unconformably overlain by the Bergman series on the south. The rocks are mainly mica-schists and quartz-mica-schists, in both of which the essential minerals are biotite and quartz. There is also some much-altered greenstone or amphibole-schist. Locally the mica-schist becomes graphitic, graphite bodies one-eighth inch in diameter being noted, and in some cases the rock carries much secondary quartz, both in small veins and in lenticular bodies. Some iron pyrite is also present, which on oxidation gives a reddish-brown color to the rock. The quartz veins tend to follow the schistosity and are often locally contorted and twisted. Some carry irregular veinlets or stringers of epidote.

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[a] Brooks, A. H.; Richardson. G. B.; Collier, A. J., and Mendenhall, W. C., Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska: Special publication U. S. Geol. Survey, 1901.

[b] Graptolites were found by Messrs. A. H. Brooks and L. M. Prindle along the northern base of the Alaskan Range in the summer of 1902.

[c] Correlation papers, Neocene: Bull. U. S. Geol. Survey No. 84, pp. 248–249.

[d] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S Geol. Survey, pt. 2, 1900.

[e] Ibid.

[f] The name Totsen is derived from the term Totsenbetna—formerly applied by the natives to Wild Creek—by dropping the final syllables, which signify river. On the map accompanying the writer's report on the expedition of 1899, and on that in Mendenhall's report of 1902 (Prof. Paper U. S. Geol. Survey No. 10), this name was erroneously applied to the stream which is now called John River, but which Allen designated Fickett's River. The word was spelled Totzenbitna by Allen. It is said to mean *lune*, the waterfowl.

The series is believed to be essentially of sedimentary origin, but the sedimentation seems to have been accompanied by basaltic flows, which were later sheared with the sedimentary beds, giving rise to amphibolite-schist, of which the most prominent strip, having an apparent width of several miles, occurs near the southern part of the belt occupied by the series. Here the rock, judging from the bent and crushed remnants of feldspar and augite shown under the microscope, is plainly of igneous origin. Though on account of faulting and folding there is doubtless some duplication of the rocks in the Totsen series, its total thickness, judging from the prevailing dip and distance across the strike, is 6,000 to 7,000 feet.

Structure.—The Totsen series, like the older rocks composing the range, trends approximately east and west, and though the series as a whole has been intensely folded, the dip in general is monoclinal, being, so far as observed, southward, at angles of 60 to 80°; but in the northern part of the belt, John River Valley, for a distance of several miles, seems to follow a north-south syncline in the series. The series is traversed by the major northeast jointing of the range, and by a secondary structure at nearly right angles to the major jointing. Cleavage was noted at a few localities, but apparently much of this has been obliterated by disturbance.

Age.—The Totsen series is represented in the geologic section as it appears to occur in the field, namely, above the Skajit series. It thus seems to be younger than the Skajit, but the actual contact between the formations was not seen, as is shown by the gap in the section, and the age relations here indicated can not be demonstrated. Furthermore, while the Totsen series, so far as observed, consists essentially of rocks that seem undoubtedly to belong to the class of older crystalline schists found in Alaska, and can not be correlated with the Fickett series, it should be noted that the observations made were confined to the line of traverse along John River, and the mountains in this part of the field not having been ascended, it is possible that the series may be overlain by or otherwise associated with rocks younger than those described above. The great thickness and probable extent of the Fickett series (to be noted later) to the north of the Skajit formation, makes it not unreasonable to suppose that members of this series may occur on the south side of the Skajit anticlinorium, but this point must be determined by future investigation.

Correlation.—The Totsen series can be correlated in a tentative way, on lithologic grounds, with the Lake quartz-schist[a] of Chandlar River. It is less evidently of sedimentary origin, is more micaceous, and contains much less quartz and more greenstone-schist, of igneous origin. In some localities, however, it very much resembles the more altered phases of the schists to the east of the Koyukuk, in the Slate Creek diggings, which also have been correlated with the Lake quartz-schist of Chandlar River. That the Totsen series extending beneath the younger formations in the Koyukuk Valley may connect with the Slate Creek schists is not improbable, especially since the Bergman series, which occupies a large part of the intervening Koyukuk Valley, seems to rest unconformably upon both.

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[a] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 474.

STUVER SERIES[a] (PRE-DEVONIAN).

Character and occurrence.—The next of the older groups of rocks to be considered is the Stuver series, comprising the oldest rocks exposed in the northern portion of the Endicott Range, and apparently forming the core of the north axis. (See section on Pl. III.) The rocks of this series are principally conglomerates, with interbedded layers of quartzite, which toward the top pass into slate and shale. The pebbles composing the conglomerate are practically all siliceous and consist of black, slate-colored, red, green, and bluish flint and milky-white quartz. They range in size from less than an inch in diameter to cobbles, and in a few instances approach bowlderets. The cement is siliceous, usually dense, and often contains grains of cryptocrystalline or aphanitic silica, undoubtedly derived from the same parent rock as the pebbles. Great force is required to break the rock with the hammer, and, when broken, the fracture plane is almost invariably found to take a direct course, traversing any pebbles, though perfectly sound, that may lie in its path; in fact, the cementation is so firm as to form of the conglomerate, as a whole, a rock substantially as hard as the hardest flint pebbles that are included in it.

The various colors of the pebbles in the conglomerate make it a very conspicuous rock, so that it is easily recognized where its fragments occur in Pleistocene and intervening formations. These fragments are conspicuous in the Lower Carboniferous rocks succeeding the Lisburne series, and are also represented in the Lower and Upper Cretaceous and in the Tertiary formations. No one of the parent rocks from which the various types of flint pebbles of the Stuver series have been derived has yet been observed. The specimens found in the placer mining gulches to the northeast, on the west side of the Koyukuk, and referred to by the prospectors as "emerald" and "adamant," probably represent flint pebbles derived from the Stuver conglomerate.

The interbedded quartzites in the Stuver series are medium grained and exceptionally hard and siliceous, and are usually of a gray or sometimes a pinkish or reddish color, while the slate is dark.

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[a] The name applied to this series is taken from Mount Stuver, situated east of the Anaktuvuk, and named for a member of the party.

Where best exposed between the two limestone areas of the Lisburne formation to the north of the Anaktuvuk, the Stuver series, forming the lower part of the longer limb of an anticline, dips southward at an angle of 30° and passes beneath the limestone of the Lisburne formation. The relation of the two formations immediately at the contact is concealed by talus, but near by begins an exposure which, extending for several miles along the front of the mountains, shows the Lisburne formation dipping southward at an angle of 20°, this dip being but 10° less than that of the Stuver series, which, as it nears the Lisburne formation, gradually decreases southward. From this it is inferred that the Lisburne, where not faulted, probably rests conformably on the Stuver series. If any unconformity exists, it must be very slight.

As shown on the geologic map (Pl. III), the exposure of the Stuver series is limited to a narrow belt, about 5 miles in width, that trends eastward for an unknown distance from the Anaktuvuk Valley, lying between the eroded edges of the Lisburne formation. The series is also supposed to form the bed-rock floor of the Anaktuvuk Valley, beneath the glacial drift, from the north edge of the mountains for a distance of 10 to 12 miles southward, to near the southern edge of the Lisburne formation. There are some small exposures of its upper member beneath the Lisburne along the base of the mountains on both the east and the west side of the valley, while on the south it has probably been brought into contact with the Lower Carboniferous of the Fickett series by faulting. Both here and at the north edge of the series the faulting seems to be normal.

Structure.—To convey a clearer conception of the controlling conditions here, it should be noted that the Stuver series lies in an east-west zone that exhibits the most marked geologic disturbance of the region. Pronounced faulting extends southward into the range for a distance of 15 to 20 miles from its seaward face. This zone extends along the crest of the divide between the Yukon and Arctic coast drainages, in the region at the head of John and Anaktuvuk rivers, and at the southern part of the great crescent formed by the north front of the Endicott Range. The beds in a general way retain the east-west trend noted in the older Skajit and Totsen series. Roughly considered, the uplift, which, judging from sediments in the post-Paleozoic rocks and the unconformable relations of these to the Paleozoic rocks, seems to have been going on since middle or late Paleozoic time, apparently took place in the form of a broad anticline, whose longer limb extends with gentle slope southward and whose shorter limb forms in part the north front of the range. Elevation was accompanied by faulting. The thrust or movement came from the south and apparently produced an overturned fold in the terranes forming the crest of the anticline. The faulting which accompanied this movement broke the beds into several great fault blocks. Erosion followed, which finally brought the Stuver series to view along the axis of the fold. These are apparently the lowest and oldest rocks exposed in the northern part of the range.

Toward its northern limits and the crest of the fold, as has been noted, the Stuver series dips southward at an angle of 30°. But still nearer its northern limits, practically at the crest of the fold, the beds have been strained, bent downward, and broken, and finally terminate in a well-defined fault scarp, as shown in the section on Pl. III. This scarp trends a little south of east and is visibly pronounced for at least 5 or 6 miles. Along this distance, in the higher part of the mountains, the edges of the broken, hard conglomerate beds forming the scarp are distinctly exposed, generally dipping about 30° S., while at a lower elevation along the face of the scarp the broken-off portions of the same strata have dragged behind along the lower face of the scarp and stand nearly on edge, dipping northward at an angle of 80°. These nearly vertical beds of the Stuver series are met at the contact on the north by the limestone of the Lisburne formation, which dips south at an angle of 75° to 80°. (See section on Pl. III.) The contact of the two formations thus forms a reentrant angle of 25°, opening upward.

The conglomerate of the Stuver series, toward its north edge and along the fault scarp, is intersected by two systems of jointing about equally pronounced. One system trends east and west, with dip vertical; the other nearly north and south, with dip to the east at an angle of 80°. On the top of a low mountain along the edge of the scarp the same hard conglomerate is finely laminated by a well-marked cleavage trending N. 60° E. and dipping northwestward at an angle of 45°.

No estimate can be formed of the thickness of the Stuver series, as its lower limits are unknown. The exposed portion shows a thickness of at least 2,000 feet.

Age.—The Stuver series, from its position underneath the Lisburne series, which on paleontologic evidence is considered to extend to below Middle Devonian, is certainly not younger than Lower Devonian, and it is regarded as probably pre-Devonian.

Correlation.—No other Alaskan rocks with which it may be correlated are known to the writer. Sediments, notably of fine conglomerate, containing materials similar to those forming the conglomerates of the Stuver series, have been noted in the Mission Creek series of the Yukon district; but probably these, like the sediments derived from the Stuver series and now found in the Tertiary and other formations on the Arctic slope, have been many times deposited and reworked since they were derived from their original source.

LISBURNE FORMATION (DEVONIAN).

Character and occurrence.—Lisburne formation is the name here employed to designate the limestone, with some shale, occurring next above the Stuver series at the head of Anaktuvuk River. The name is taken from Cape Lisburne, where apparently the same formation, consisting of limestone and shale, occurs. On the Anaktuvuk the formation occupies a belt 15 or more miles in width, extending north and south along the valley. Toward the west the belt narrows and appears to soon be delimited on the southwest by the fault scarp of Contact Creek, and, farther west, by the Carboniferous of the Fickett series; while to the east of the Anaktuvuk it seems to widen. The westward extension of the formation may, however, somewhat exceed that represented on the map before it disappears beneath the Carboniferous, for the mountains south of Contact Creek were not ascended.

Where examined along Contact Creek, the north side of the valley for several miles consists of a steep wall, or fault scarp, of the Lisburne limestone, similar to that forming the scarp along the Anaktuvuk Valley on the east; while the rocks directly opposite, on the south side of the valley, less than three-fourths mile distant, are Carboniferous quartzite and conglomerate of the Fickett series. Northwest of this locality, however (as shown in Pl. IV, *B*, a view looking westward from the south edge of a Lisburne fault block near Contact Creek), the Lisburne, still forming the crest of the axis, with an elevation of about 6,500 feet, is less disturbed. The beds on the right, which show a marked increase in shale at the expense of the limestone, dip northward toward the base of the range, while farther west the Lisburne seems gradually to disappear beneath the Fickett series as a broad anticline, with the longer limb sloping gently southward and the shorter dipping more steeply northward, and probably playing an important part in forming the steep north front of the range, as has been shown to be the case to the east of the Anaktuvuk Valley.

In the foreground of Pl. IV, *B*, the Lisburne extends all the way across the field from left to right, but the sculptured cirque topography forming the top of the mountains in the left background lies in the slate and quartzite of the Fickett series, which, to the northwest, seems to overlie the Lisburne and form the crest of the range, and probably also descends the north slope and underlies the Mesozoics of the Anaktuvuk Plateau at the north base of the mountains.

The rocks of the Lisburne formation may be characterized for the most part as medium-bedded semicrystalline limestone of impure white or gray color. They weather gray, light rusty brown, or chocolate. They form the mountains that rise to a height of 2,500 to 3,000 feet above the floor of the Anaktuvuk Valley. Near the summit (see Pl. X, *B*, and fig. 4) occur two beds of intercalated shale, each apparently several hundred feet thick, and containing some thin layers of dark-gray limestone.

On the east the extent of the formation is unknown. On the south it is apparently in contact with the Carboniferous, while in descending the slope of the mountains on the north it disappears beneath a mantle of glacial till, where, judging from the topography, it is probably soon met and overlain by Mesozoic strata, which probably rest unconformably upon it at this point. (See. fig. 4, p. 51.)

Judging from exposures observed in the region of the Anaktuvuk, the thickness of this limestone formation is probably a little over 3,000 feet.

Structure.—The entire area of the Lisburne formation here considered is deeply involved in the system of faulting and disturbed blocks referred to under the heading "Stuver series." As viewed from the Anaktuvuk Valley, looking either east or west (see section on Pl. III; also fig. 4 and Pl. X, *B*), the Lisburne series reveals but little of the disturbance it has undergone. On the southwest, however, toward Contact Creek, the rocks have been folded and broken into blocks, which in some instances are highly tilted. The fault on the west side of the Anaktuvuk, shown on the right of fig. 4, probably represents the westward extension of the same fault that gave rise to the scarp along the northern edge of the Stuver series, which series however, has not here been brought to view. At the north base of the mountains, west of the Anaktuvuk, the Lisburne formation disappears beneath the covering of glacial drift with a dip of 60° to the north. East of the Anaktuvuk it similarly disappears beneath the drift, but with an opposing dip at an angle of 75° S., against the fault scarp of the Stuver series, as shown in the section on Pl. III. Between these two localities the Stuver series probably attains a steep westerly dip, of which there is some suggestion along the north edge of the valley, or a portion of the valley may be traversed by a north-south fault extending from the north edge of the mountains to the southern limits of the Stuver series.

In certain localities, notably on the south side of the Anaktuvuk, the Lisburne is cut by a close jointing, trending N. 27° E., with dip southeast-east at an angle of 85°, dividing the rocks into thin slices from 2 to 8 inches in thickness.

There can be but little doubt that the faulting between the Lisburne and the Fickett series continues eastward and connects with that along the southern edge of the Bettles series, on Koyukuk and Chandlar rivers. Its alignment with the boundary of the Bettles series, as located in a previous year's work,[a] is shown on the geologic map, Pl. III.

Age.—The most convenient disposition to make of the Lisburne formation would be to include it with the Fickett series and call the group Carboniferous and Devonian, since both Carboniferous and Devonian fossils occur freely in the stream gravels of the upper John and Anaktuvuk rivers, and none of the fossils found in place were sufficiently well preserved for identification. On lithologic grounds, however, the Lisburne formation can be set apart as quite distinct from the Fickett series, which it also seems to underlie. Therefore, on the basis of the Devonian fossils found in detached fragments of rock on the surface of the formation near the top of the mountains, and on the lithologic similarity of the rock attached to these fossils to that of the Lisburne formation, the formation is provisionally referred to the Devonian.

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[a] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pl. lx.

The fossils from the Lisburne formation collected by the writer have been identified by Mr. Charles Schuchert as follows:

Fossils of the Lisburne formation.

Locality 455.
  Productella (2 species).
  Platystoma.
  Zaphrentis.
  Fenestella.
  Unitrypa.
  Eridotrypa, nearly identical with E. barrandei (Nicholson) of the Middle Devonian.
Localities 460 and 462.
  Spirifer disjunctus.
Localities 496, 498, 499, 501, 523, and 524.
  Diphyphyllum (1 species).
Locality 500.
  Zaphrentis.
Locality 528.
  Aulocophyllum.
Locality 533.
  Zaphrentis.
  Rhombopora.
  Fenestella.
  Hemitrypa.

Localities 455 and 528 appear to be of one formation of the Middle Devonian. The species present suggest very much the Athabasca-Mackenzie Middle Devonian, collected many years ago by Kennicott and described by Meek in the Transactions of the Chicago Academy of Sciences.

Localities 460 and 462.

Spirifer disjunctus, one of the fossils characterizing the Upper Devonian. The same species is also found in the Peace, Hay, and Liard River regions of Arctic Canada.

Localities 496, 498, 499, 501, 523, and 524.

Diphyphyllum (1 species). This genus extends in America from the Upper Silurian to the close of the Middle Devonian, and will probably also be found in the Upper Devonian, so that, unsupported by other evidence, it does not indicate an exact horizon. This or a very similar species has been found at or near the mouth of Mackenzie River in Devonian rocks.

Localities 500 and 533 are probably also of Devonian age.

Correlation.—On lithologic grounds it appears that the Lisburne formation can safely be correlated with the medium-bedded, unsheared limestone portion of the Bettles series, which is best exposed near the mouth of Bettles River, on the Koyukuk,[a] and it probably continues to the head of Chandlar River. Thus this limestone formation extends from the region west of the Anaktuvuk eastward 100 or more miles, and the presence of Devonian still farther eastward, to the north of the Chandlar, is rendered highly probable by a few fossils collected from the Chandlar River gravels in 1899 by the writer.[b] These fossils, a list of which follows, were identified by Dr. George H. Girty, whose statements thereon are here inserted.

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[a] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 475.
[b] Ibid.

Paleozoic fossils from the Chandlar River gravels.

Locality 211. Indeterminable.
Locality 22. Syringopora sp. 1.
Locality 2. Syringopora sp. 2.
Locality 47. Spirifer, disjunctus type.
Locality 5. Cyathophylloid coral.
Locality 203. Crinoid stems.

Syringopora, so far as known, is not found above the Carboniferous; therefore 22 and 2 can be referred, with little doubt, to the Paleozoic.

The spirifer of locality 47 represents a type which is not found below the Devonian, and is, in a measure, restricted to rocks of that age. This spirifer can pretty safely be referred to the Devonian, and if, as I suspect, the form is *Sp. disjunctus* itself or one of its close allies, probably to the Upper Devonian.

The coral found at locality 5 probably belongs to the genus *Acervularia*. The age indicated is certainly Paleozoic, and probably Devonian.

The crinoid fragments found at locality 203 indicate nothing positive as to age. From their character and abundance I should be inclined to determine the horizon as Paleozoic.

It should also be noted that the trend of the series continued still farther eastward, beyond the Chandlar River Basin, strikes the Porcupine near the Lower Ramparts, where Devonian forms were collected by Kennicott,[a] and where Mr. McConnell, of the Canadian geological survey, reports the limestone to yield such fossils as *Atrypa reticularis*, with fragmentary specimens of corals referable, in part at least, to the Devonian.[b] It seems highly probable that the Lisburne formation may also be correlated with the similar limestone and shale formation occurring at Cape Lisburne, which, though nearly 400 miles distant, undoubtedly represents the westward continuation of the same mountain axis. (See Pl. V and fig. 1, p. 40.) This suggestion is based, in a measure, on the statements of different persons who have found Paleozoic fossils in the Cape Lisburne region, and more especially on the recent reports of Mr. H. D. Dumars and Mr. A. G. Maddren. The fossils collected by Mr. Dumars in the region, with notes by the collector, have been presented by Mr. Maddren to the United States National Museum, where they have been examined by Mr. Schuchert, whose communication on them to the writer is as follows:

Paleozoic fossils from the Cape Lisburne region.

There is an interesting coral fauna of Middle Devonian age from "limestone cliffs 4 miles south of Cape Lisburne, just south of the mouth of a considerable stream, where the rocks strike east and west, and dip south at 45°" (Dumars). This limestone contains—

Endophyllum, 2 species.
Syringopora, near S. tabulata.
Syringopora, near S. perelegans.
Diphyphyllum, near D. simcoense.
Diphyphyllum, near D. stramineum.
Zaphrentis, probably 2 species.

This limestone appears to be the same formation as that discovered by you last summer [at head of Anaktuvuk River] at localities 496, 498, 499, 501, 523, and 524, but more particularly at 455 and 528.

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[a] Trans. Chicago Academy Sci., vol. 1, 1867.

[b] Ann. Rept. Geol. Survey Canada, new series, vol. 4, 1890, p. 133 D.

In his field notes referring to this locality Mr. Maddren states that the limestones forming the cliffs referred to contain corals and other fossils and also veins of calcite. Fig. 1 (p. 40) is a profile section of the limestone and shale as sketched by Mr. Maddren at a locality a short distance south of the point where the fossils were found in place. The section includes Cape Lewis and Cape Dyer. So far as known, however, no fossils were found in the limestone represented in it. Cape Dyer is described as the sea terminus of a limestone range, about 1,000 feet in height, which trends inland in an easterly direction, the rocks striking east and west and dipping 35° N. In the valley between Cape Dyer and The Ears there is said to be a syncline of shale containing an exposure of coal along a sea cliff that rises from 50 to 100 feet above tide. The occurrence of coal here would seem to indicate the presence of some other horizon, probably Carboniferous or Mesozoic. According to Mr. Maddren the limestone beds at Cape Lewis also dip north and expose a thickness of 800 to 1,000 feet.

We may also note that the Middle Devonian discovered by Mr. Spurr in southwestern Alaska,[a] in the Kuskokwim country, is considered by Mr. Schuchert as about the same as that on the Anaktuvuk. The same is true of the forms collected by Mr. Brooks in southeastern Alaska.[b]

Distribution.—The thickness of the Lisburne formation in the mountains on the Anaktuvuk and at Cape Lisburne on the coast, and the important part it plays in the constitution of the Endicott Range and the continuation of these mountains westward to at least the one hundred and fifty-second meridian, as discovered by Howard,[c] as well as the general regularity in the disposition of the rocks, seem to render it highly probable that that formation is continuous between the Anaktuvuk and Cape Lisburne. Its lithologic resemblance to the limestones of the Bettles series on the Koyukuk[d] and the Devonian fossils found by the writer in the Chandlar River district, and by Kennicott and McConnell farther east on the Porcupine, would lead to the inference that the Lisburne formation, or at least the Devonian, forms a pretty constant component of this northern Rocky Mountain range from Cape Lisburne eastward throughout northern Alaska, for a distance of 600 or more miles, nearly to the international boundary and probably beyond it.

FICKETT SERIES (CARBONIFEROUS).

Character and occurrence.—The Fickett series, so named from the Fickett River of Allen (now called John River), comprises rocks of very diverse character, ranging from chloritic schists and phyllites on the south, through impure limestone, slate, sandstone, quartzite, and grit, to hard conglomerate on the north. As shown in the discussion of the Skajit, Totsen, Lisburne, and Stuver series, the Endicott Mountains contain two geologic axes, a northern and a southern, both composed of the older Paleozoic rocks, and, as represented on the geologic map and section (Pl. III), the Fickett series lies essentially in what appears to be a broad trough between these two axes. This trough or syncline, judging from the unconformity of the Fickett series to the Skajit and Lisburne formations, and the difference in character of the sediments, was probably occupied by an arm of the sea in late Paleozoic time, when the axes on the north and the south seem to have stood above sea level; and the sediments of the Fickett series, judging from their calcareous content, were probably in part derived from these Paleozoic land areas.

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[a] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 179.

[b] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902, p. 21.

[c] Stoney, Lieut. George M., Naval Explorations in Alaska, U. S. Naval Institute, Annapolis, Md., 1900, p. 70.

[d] Schrader, F. C., Reconnaissance along the Chandlarand Koyukuk rivers, Alaska; Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 475.

Here the Fickett series has a width, or north-south extent, of about 50 miles. On the south its edges appear to rest unconformably on the eroded Skajit formation of the southern axis, as shown in the geologic section, while owing to the faulting at the head of John and Anaktuvuk rivers its relations to the older rocks of the northern axis are not definitely revealed. It seems, however, to meet the Stuver series and the Lisburne formation by fault contact, as has been indicated. To the north of this contact, so far as observed in the region of the Anaktuvuk, all trace of the series in place seems to have been removed by erosion. To the west, however, beyond the limits of the fault-block system of the Devonian, about 20 miles from the Anaktuvuk, it seems to overlie the Lisburne formation, and probably extends beneath the Mesozoics at the north base of the range. From the occurrence of Carboniferous fossils in the stream gravels it is inferred that the same conditions probably prevail to the east of the Anaktuvuk, but they have not thus far been actually observed.

Beginning on the south slope of the north axis of the range, the lower part of the Fickett series, as it seems to be, consists of dark shale, schistose slate, and apparently some dark limestone, which is succeeded by quartzite, grit, and conglomerate. The sediments in the quartzite, and more especially those in the grit and conglomerate, though they are often fine, bear a marked resemblance to the vari-colored conglomerate of the Stuver series, from which they seem undoubtedly to have been derived. The quartzite, grit, and conglomerate are hard and flinty, the grains and pebbles being thoroughly united by a siliceous cement. The best exposure of these rocks that was seen is that at Fork Peak, on John River, east of camp July 12, from which point for about 15 miles northeastward, to beyond the Anaktuvuk portage, they present a steep face to the northwest, overlooking the upper part of John River Valley. Here the dip is gently south or southeast. Apparently these same conglomerates and grits were also encountered in the lower reaches of a deeply cut gulch about 20 miles south of Fork Peak, west of the mouth of Hunt Fork. Toward the top of Fork Peak the grit and quartzite give way to dark schistose slate and dark-gray micaceous sandstone.

Southward, at a geologically higher horizon, gray sandstone, limestone, gray schist, some quartzitic schist, slate, and conglomerate are encountered. These rocks are medium layered, variously interbedded, and more or less sheared. In the region of Hunt Fork a dark-gray or bluish schistose sandstone and soft slate become predominant. Apparently ascending in the column, still farther southward, the rocks become for the most part very fine-grained gray or bluish quartz-schist, with finally greenish chloritic schist and slate, which continues to the southern edge of the series, where it rests unconformably on the Skajit limestone formation. The quartzitic schist and the green chloritic schist often carry considerable quartz in small veins and stringers, trending more or less parallel with the schistosity and the bedding. But exceptions occur, as shown in Pl. XI, *A*, where a species of gash veining breaks across the bedding. This quartz frequently is most abundant in the bights of sharp folds and along lines of strain and breaking. So far as observed, the veins carry no valuable metals.

Besides the above-noted rocks, light-gray and dark or black limestones, apparently belonging to the series, but not met in place along the route traversed, were sighted and studied with the field glass both southeast and southwest of Fork Peak. These limestones, judging from the resemblance to the specimens found in the stream gravels, are the mother rocks of the fossils occurring so abundantly in the streams. Their position in the geologic section seems to be above the conglomerate, grit, and quartzite portion of the section and near the dark schistose slate and dark-gray micaceous sandstone, as shown to some extent in Pl. VII.

Structure.—The Fickett series, like the other Paleozoics of the range, has been subjected to faulting and folding, incident to mountain building. The general structure, however, seems to be monoclinal, with strike and trend east and west and dip south at angles of 20° to 45°. The dip may vary, however, from southeast in some localities to southwest in others, while in certain cases the rocks lie nearly horizontal or dip very gently north. The prevailing southerly dip of the series as a whole seems to point to a greater and probably later elevation in the northern than in the southern part of the range since the Fickett was laid down.

The series is finely cut in some localities by the major nearly northeast-southwest jointing, whose planes are frequently slickensided and usually dip 70° to 80° NW. Slight movement, or normal faulting, has frequently taken place along them. The rocks are also traversed by a secondary set of joints, trending nearly northwest and southeast, with dip nearly vertical, or in some instances 60° to 80° SW.

The schists, and notably the slates, often exhibit excellent cleavages, a good instance of which is shown at Crag Peak, 10 miles south of Hunt Fork and 4⅛ miles west of John River. Here the cleavage trends N. 35° E. and dips northwest at an angle of 85°. Four miles north of this point, on the west side of John River, occurs another good instance, in which the cleavage trends N. 70° E., with dip to the north at an angle of 45°. Also where the river crosses the sixty-eighth parallel a cleavage is found trending east and west, with dip south at an angle of 30°.

Age.—No fossils have been found in place in this series, but on the basis of abundant Lower Carboniferous forms obtained in the stream pebbles of the region, and the lithologic resemblance of these pebbles to the rocks of the series, and also from the relation of the series to the Lisburne formation (which is considered Devonian and seems to underlie it), the Fickett series is provisionally assigned to the Lower Carboniferous. Following is a list of the fossil forms collected by the writer within the area occupied by the series, largely on the headwaters of John and Anaktuvuk rivers. They have been identified by Mr. Schuchert, who reports as follows:

Fossils from the Fickett series.

Locality 493. Lithostrotion (of the group in which the corallites are not in close embrace).

Locality 495. Spirifer striatus Martin, Productus scabriculus Martin, and Spirifer near S. neglectus Hall.

Locality 513. Productus scabriculus Martin.

Locality 520. Productus semireticulatus Martin.

Locality 521. Spirifer striatus Martin; Productus, a very small undetermined species, and Cystodictya nearest to C. lineata.

Locality 522. Spirifer striatus Martin and Fenestella.

Locality 525. Spirifer striatus Martin and Spiriferina cristata Schlotheim?

Locality 534. Streblotrypa near nicklesi Vine; Fenestella, several species, one of which is near F. cestriensis Ulrich; Cystodictya, Pinnatopora, and Rhombopora.

The above eight localities represent one formation, in the upper portion of the Lower Carboniferous. This fauna, however, is unlike that of the Mississippi Valley in that it does not have its characterizing fossils, as the screw-like bryozoan *Archimedes* and the blastoid genus *Pentremites*.
parisons must be deferred until larger collections are at hand.

Localities 497 and 529 have a *Syringopora* much like *S. multattenuata* of the Upper Carboniferous. This genus, however, has little stratigraphic value, but the development of the species present is indicative of Carboniferous.

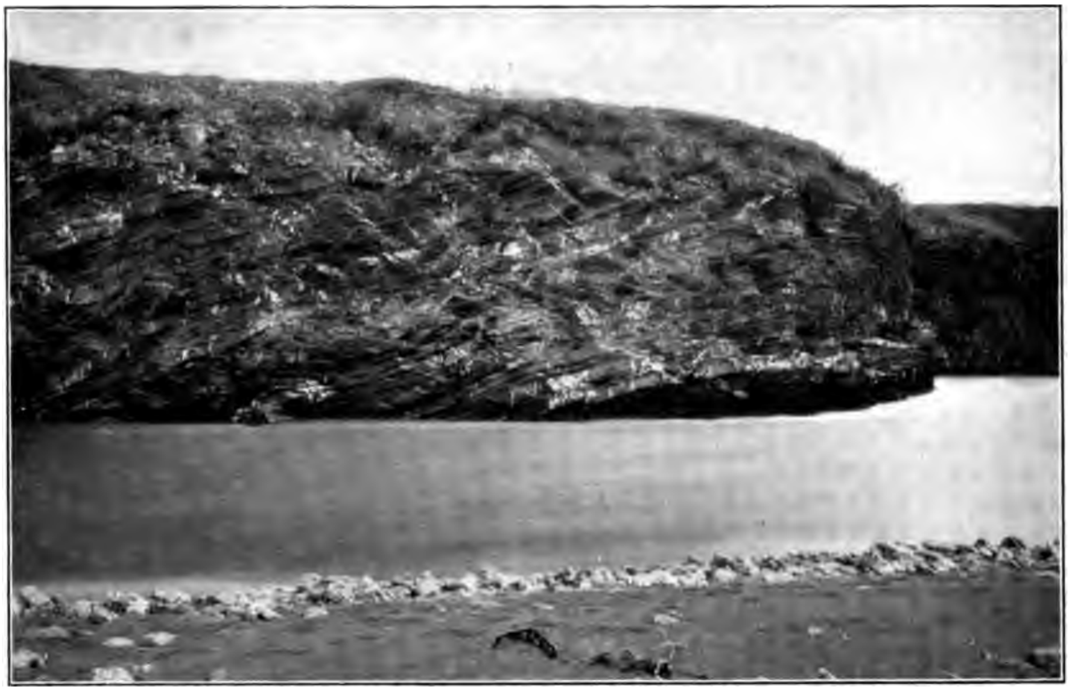
Localities 511, 518, and 454 are represented by a crinoidal limestone, apparently the same as at localities 525 and 521 and probably from the horizon of the latter.

Localities 463 and 464 represent another horizon, since the lithology is quite different from any of the other localities. The only fossils present are large crinoidal columns like those of the Lower Carboniferous.

Locality 461 also has large crinoid columns and may represent the Lower Carboniferous.

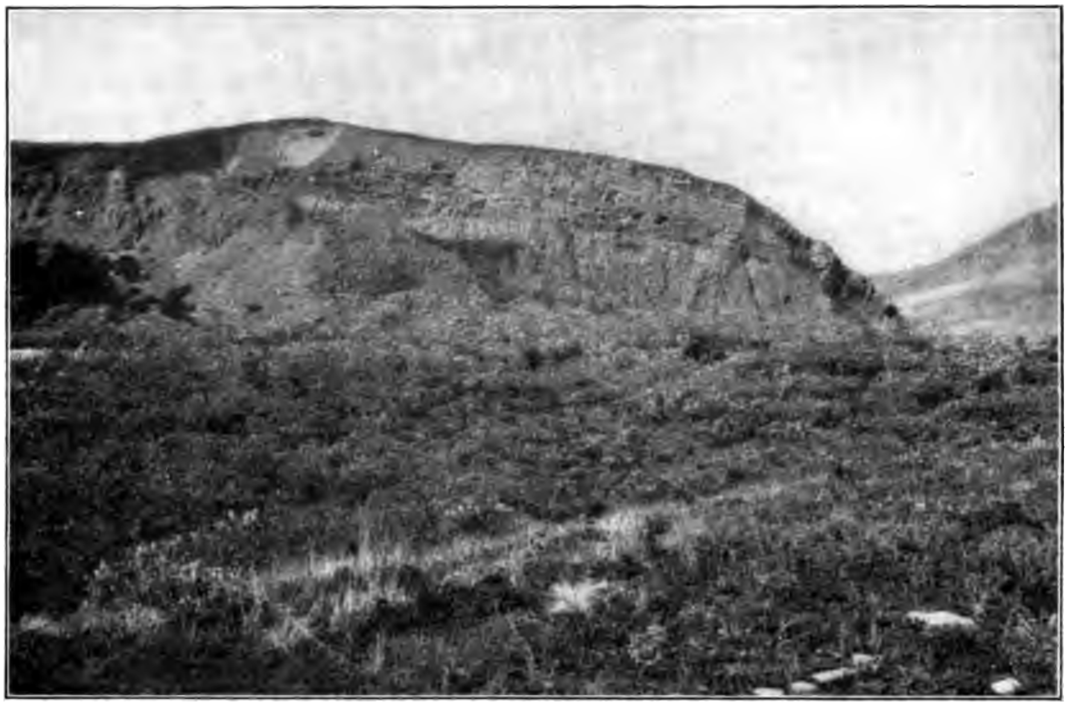
The above localities probably all represent the same Lower Carboniferous formation as that of the specimens from localities 493, 495, 513, 520, 521, 522, 525, and 534.

Locality 519 has *Fenestella*, *Cystodictya?* and crinoid columns. The material is unsatisfactory and all I can do is to state that it indicates either Devonian or Carboniferous.



A. QUARTZ GASH STRINGER VEINING IN FICKETT SERIES ON JOHN RIVER, IN ENDICOTT MOUNTAINS.

Looking southeast.



B. STRUCTURE IN ANAKTUVUK SERIES ON ANAKTUVUK RIVER.

Looking N. 10° W.

In referring the series to the Lower Carboniferous, however, it should be borne in mind that the fossils were nearly all found in the northern part of the field, where they have apparently come from near the lower part of the section, and since the series is possibly 8,000 to 10,000 feet in thickness, it may extend not only into Upper Carboniferous but possibly into Lower Mesozoic.

Correlation.—Carboniferous fossils have been collected by Spurr[a] and Collier on the Yukon above Circle, by Mendenhall and the writer in the northern part of the Copper Basin, and by Dall in southeastern Alaska, on Kuiu Island, but these all seem to be Upper or Permo-Carboniferous, and therefore afford no ground for close correlation of the rock occurring there with those of the section here considered.

Independent of paleontologic evidence, on purely lithologic grounds, some of the gray schist, sandstone, and limestone beds of the series toward the northern part were associated by the writer in the field with the West Fork series of Chandlar River,[b] which is regarded as possibly the source of some of the Paleozoic fossils found in the river gravels below that point, and which has been relegated by Doctor Girty to Carboniferous or Devonian.

Carboniferous forms are reported to have been collected on Captain Beechey's voyage,[c] 1825–1828, on the northwest coast between Cape Beaufort and Cape Thompson (see Pl. V). More recently, in the Cape Lisburne region, plant remains have been collected by Mr. Dumars which have been identified by Mr. David White as a small species of *Lepidodendron*, related to *L. chemungense*, and a small form of *Stigmaria ficoides*, indicative of Carboniferous age. This denotes at least the presence of Carboniferous rocks in the Cape Lisburne region, which, on future investigation, may be correlated with the Fickett series, and suggests that the rocks of the two regions may be continuous in the mountains lying between them, as the Devonian is supposed to be. (See p. 66.)

In fact, if topographic criteria be taken into account—namely, the continuation of the mountains eastward beyond the international boundary—with what has been said of the occurrence of the Lisburne formation, it may here be briefly stated, in concluding the subject of Paleozoic rocks, that the present exploration, together with the evidence previously collected in the region to the east and that to the west, toward Cape Lisburne, seems to indicate beyond question the extension of a well-developed belt of Paleozoic rocks across northern Alaska, coinciding with the trend of the Rocky Mountains from the one hundred and thirty-fifth meridian, near the Mackenzie, to the one hundred and sixty-sixth, at Cape Lisburne, a distance of nearly 1,000 miles.

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[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898.

[b] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900.

[c] Voyage of Captain Beechey to the Pacific and Behring's Straits, London, 1836, pp. 378–405.

In the Cape Lisburne region, as noted, the belt has a known width of nearly 75 miles and the rocks terminate in abrupt sea cliffs. The thickness of the section here is not known, but from what has been learned of the attitude of the rocks, it is judged to be considerable, since nowhere do older rocks appear to be exposed beneath these Paleozoics; from which it seems safe to infer that the latter probably extend far seaward as a submarine feature; and as this part of the ocean is known in the main to be shallow, it seems not unlikely that the same formations may extend across its floor and appear on the Siberian coast. It may be noted, however, that Doctor Dall, who visited this coast, reports that the rocks on portions of it are essentially crystalline or igneous. Some lignite occurs on Wrangell Island, but we do not know that Paleozoic or other formations occur there.

MESOZOIC ROCKS.

CORWIN SERIES (JURA-CRETACEOUS).

Character and occurrence.—The name Corwin is proposed for a series of sedimentary rocks which are younger than the Fickett series and older than the Anaktuvuk series (next to be described). The name is taken from Corwin Bluff, in the Cape Lisburne region (see Pl. V), where the well-known coal mines of this name are located, and where rocks typical of the series are well exposed.

The rocks in the main have a strong lithologic resemblance to the Anaktuvuk series, and seem to be closely related to it in geographic and stratigraphic position, but as they are not known to occur in the interior along the route followed by this traverse, they will not be found represented on the geologic map nor in the geologic section. However, sufficient has been seen of the rocks along the coast from Wainwright Inlet to near Cape Lisburne to lead to the inference that they probably form a part of the trans-Alaskan Rocky Mountain system; and on topographic, geographic, and lithologic grounds, as shown in what follows, it has been concluded that they are intermediate between the Fickett and Anaktuvuk series, a view which is also supported by paleontologic evidence. The series contains the Wainwright, Cape Beaufort, Thetis, and Corwin coals, most of which are of good grade. The inland extension of the series is also further suggested by the occurrence of coal on the Colville, reported by Howard and by Reed (see p. 31).

As observed along the coast, the Corwin series seems to extend from near Wainwright Inlet, latitude 70° 37′, longitude 159° 45′, southwestward a distance of 180 miles or more, nearly to Cape Lisburne (see Pl. V). Beyond this point, farther inland, it seems to give way with marked unconformity to the Paleozoic rocks forming the core of the mountains terminating in the sea cliffs at Cape Lisburne and the coast south of that point (fig 1, p. 40).

other trends nearly northwest, approximately parallel with the strike of the rocks, and dips northeastward at an angle of 60° to 70°. These jointings, however, do not cut up the rock greatly, not nearly so much as do those in the Lower Cretaceous rocks of the Anaktuvuk series in the interior.

Age.—Remains of fossil plants found in the Cape Beaufort region, and more particularly in the shale near the Thetis mine at Cape Sabine, by Mr. Dumars, Mr. Woolfe, and others, have been identified[a] by Professor Fontaine and Doctor Ward as not older than the Oolitic of the Jurassic, nor younger than the Lower Cretaceous, and as probably transitional between the two. Similar evidence is afforded by fossil plants collected by the writer on the coast about 7 miles southwest of Wainwright Inlet, which have been identified by the same authorities as—

Nageiopsis longifolia Font.
  Older Potomac of Virginia (Lower Cretaceous).
Podozamites distantinervis Font.
  Older Potomac of Virginia (Lower Cretaceous).
Baiera gracilis (Bean) Bunbury.
  Oolite of Yorkshire, England (Jurassic).

On the above evidence, therefore, the Corwin series is provisionally assigned to the Jura-Cretaceous.

Correlation.—Except the Kennicott[b] formation in the Copper River district, no Jura-Cretaceous rocks with which the Corwin series can be correlated have thus far been found in Alaska.

ANAKTUVUK SERIES (LOWER CRETACEOUS).

Character and occurrence.—The Anaktuvuk series takes its name from the native name of the river along which it was observed by the writer. It underlies the southern or principal part of the very gently rolling Anaktuvuk Plateau, along the north side of the Endicott Range, whence, with surface sloping gently northward, it continues to form the country rock for a distance of about 50 miles, where it is succeeded by younger rocks.

Along the base of the mountains the series, judging from the topography (see Pl. IV), is believed to rest unconformably on the Devonian, or Lisburne formation. Of this, however, we have no conclusive evidence, as the actual relation between the two rocks was not seen, because of the covering of glacial drift. The first exposure of the series visited by the writer is about 8 miles from the mountains.

To the east the Anaktuvuk series is probably soon limited by the Paleozoic front of the range, while to the west and northwest it probably constitutes in part the so-called Meade River Mountains, and, continuing northwestward, may extend to the Arctic coast.

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[a] A full description of these collections, including the forms collected by the writer, will appear in Doctor Ward's second paper on the Older Mesozoic floras, to be published by the U. S. Geological Survey.

[b] Schrader, F. C., and Spencer, A. C., Geology and Mineral Resources of a Portion of the Copper River District, Alaska (a special publication of the U. S. Geol. Survey), 1901, p. 48.

The series consists essentially of impure sandstone or arkose, with a little fine conglomerate. The sandstone is usually heavy bedded, beds 6 to 8 feet in thickness being common, and it is generally fine to medium grained, but in some localities becomes so coarse as to be almost a grit. In color it ranges from dark or bluish gray to dirty greenish, while the coarser grained rock often presents a speckled or salt-and-pepper appearance, and is seen to be composed of grains of the variously colored flints represented in the Stuver conglomerate. In fact, the color of the rock throughout seems to be determined largely by the relative abundance of the different colored sediments from the Stuver series.

Northward from the mountains the rocks, though distinctly sedimentary, contain also some detritus of igneous rocks, as fragments of feldspar and some dark mineral, apparently augite or hornblende. The igneous rocks from which such sediments have been derived probably occur in the mountains lying far east or southeast of the plateau, as none were observed in the mountains in the region of the Anaktuvuk.

Conglomerate is apparently rare in the series, having been observed at but a single place—on the right bank of the Anaktuvuk about 2 miles below the mouth of Willow Creek, where it is exposed in a low point, interbedded with a few lens-like layers of sandstone. The conglomerate is typically rather fine, with scarcely a pebble exceeding three-fourths of an inch in diameter. The pebbles and cement are composed largely of sediments of the Stuver series, white quartz and dark or slate-colored flint being the most conspicuous. The pebbles are noticeable for their angularity, suggesting glaciation about the time the series was deposited. The cementation is relatively firm for a young rock, but is not comparable with that in the Stuver or Fickett series. The cement is mainly siliceous, but contains also calcareous material, probably derived from the Lisburne formation.

Owing to the low relief and the covering of drift and moss, no accurate idea can be formed of the thickness of the Anaktuvuk series, but it is estimated to be at least 2,000 feet.

Structure.—The strike of the Anaktuvuk series is approximately east and west, agreeing in this respect with the several series of rocks that compose the range to the south. Broadly considered the structure seems monoclinal. The rocks in general dip gently northward at varying angles, but subordinate gentle anticlinal and synclinal folds are present, the latter being occasionally open. These were probably caused by the same mountain-building forces that were exerted in the range to the south. This is suggested by the fact that the trend of the more pronounced folds in the plateau is parallel with the main folding of the range, as if all belonged to the same system. Besides the east-west major flexures, the plateau is also traversed by a subordinate or minor system of cross folds or warpings, with axes trending north and south, giving rise to occasional low domes, as shown in fig. 3 (p. 46), which also shows that the region has been subjected to considerable denudation.

The series is freely traversed by two systems of jointing, as shown in Pl. XI, *B*. Of these, what seems to be the dominant or major system trends nearly northwest and dips southwest at an angle of 80°, while the minor system traverses the rocks at nearly right angles to the major, trending northeast, with dip 80° SE. Both systems seem to roughly correspond in trend with the similar structures in the Paleozoic rocks in the mountains to the south.

Age.—It has been determined, on paleontologic evidence, that the Anaktuvuk series is Lower Cretaceous. It contains typical *Aucella* beds of Alaska. The first fossils collected by the writer were found 8 miles north of the foot of the mountains. Subsequently others were found at several points farther north, principally at the first cross ridge on the Anaktuvuk, and in the bluff at the mouth of Willow Creek. Of these fossils the most characteristic, as determined by Doctor Stanton, are "*Aucella crassicollis* Keyserling, or closely related forms, and are of Lower Cretaceous age.

It should be borne in mind, however, that while its Jurassic forms prevent the Corwin series from being included with the Anaktuvuk series as Lower Cretaceous, it is not improbable that the discovery of such forms in the future may place the lower portion of the Anaktuvuk series, now assigned to the Lower Cretaceous, in the Jura-Cretaceous, since no fossils have yet been found in the extreme basal portion of the Anaktuvuk rocks.

Correlation.—On paleontologic grounds the Anaktuvuk series may be directly correlated with the Koyukuk series, next to be described. The rocks of the former, however, are free from all trace of igneous intrusions, while the Koyukuk series is associated with igneous rocks,[a] as dikes, and probably also as flows.[b]

Lithologically the Anaktuvuk rocks bear little or no resemblance to the Mission Creek series, assigned to the Cretaceous by Spurr,[c] nor to the Kennicott formation or the Orca series of the Copper River district. As shown in the table of provisional correlation, several other series of rocks found elsewhere in Alaska have also been referred to the Cretaceous—the Matanuska series by Mendenhall, between Resurrection Bay and Tanana River; the Tordrillo, Holiknuk, Kolmakof, and Oklune by Spurr, in southwestern Alaska; and the Cantwell conglomerate by Eldridge,[d] in the Sushitna River region.

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[a] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 477.

[b] P. 78, this paper.

[c] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898.

[d] Eldridge, G. H., A reconnaissance in the Sushitna Basin, Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1898.

The Bergman series consists essentially of thin- or medium-bedded, impure, gray or brownish sandstone and dark slate, with some dark shale and occasionally conglomerate, but along the north it is bordered by a belt of conglomerate about 10 miles wide which is apparently the basal member. The sediments of the series have been derived very largely from igneous rocks, as is shown by the generally feldspathic constituents of the sandstones and the presence of basaltic, diabasic, and granitic pebbles or finer detritus in the conglomerate on the lower part of Alatna River and at Lookout Mountain. The supposed basal belt of conglomerate along the northern border, however, so far as it was observed in the John River region, is composed essentially of the débris of limestone and mica-schist derived from the Skajit formation and the Totsen series, on which latter it unconformably lies. This conglomerate is normally coarse, and in some instances contains bowlders.

Owing to the wide separation of the outcrops visited, data for forming an adequate estimate of the thickness of the Bergman series have not been obtained. From a general impression, however, it seems safe to suggest that it is probably at least 2,000 feet.

Structure.—The Bergman series, like the Koyukuk series to the south, has been considerably folded and somewhat faulted, but apparently to a less degree than the latter. Faulting has been observed on Koyukuk River just below Bergman and farther downstream, below Kanuti River. Though local folding has been pronounced, and the rocks are sometimes highly tilted and stand on edge, the prevailing dip of the series seems to be gently southward. On the whole the series does not seem to have received from the geologically late crustal movement the widespread tilt exhibited by both the Anaktuvuk series on the north of the range and the Koyukuk series on the south. Lookout Mountain apparently represents part of an anticlinal fold occurring in the series. Here the beds strike a little north of west and dip south at an angle of about 80°. A pronounced jointing trends northwest and dips 80° NE. A minor jointing trends north and dips east at an angle of 80°. On the north, where the beds apparently rest against the Totsen series, the dip is south at an angle of about 40°.

Age.—In 1899, owing to the presence of coal, lignite, and fragmentary plant remains in the beds, notably above Tramway Bar, and the resemblance of the beds in many instances to the Kenai formation occurring elsewhere in Alaska, it was conjectured that the rocks might be Tertiary and in part Kenai. The more extended observations made during the last season, though a large area of the series was traversed, have thrown no more definite light on the subject, for determining fossils were not found. It has been shown, however, that between Bergman and John River the series bears a marked resemblance lithologically to the Anaktuvuk series, or Lower Cretaceous, and that its rocks, on the whole, are more indurated than the coal-bearing Upper Cretaceous or Nanushuk series, both occurring in the Arctic slope region. Judging from this, and from the seemingly close relationship of the Bergman series to the Lower Cretaceous or Koyukuk series, and the bituminous character of its coal content (No. 187 in table of analyses, p. 114), it seems probable that on further investigation the Bergman series is more likely to prove to be Cretaceous than Tertiary.

NANUSHUK SERIES (UPPER CRETACEOUS).

Character and occurrence.—This series is named from Nanushuk River, the native name of the stream on which it occurs, and which flows into the Anaktuvuk north of the middle of the belt. The series lies north of the Anaktuvuk series, which it seems to overlie unconformably, and is itself in turn overlain by the Tertiary Arctic coast strata, with which its relations are apparently also unconformable. The unconformity between the Anaktuvuk and the Nanushuk is inferred from the difference in the topography and the marked change in the character and attitude of their rocks. In the most northern observed exposure of the Anaktuvuk the dip is north, while in the most southern of the Nanushuk it is steeply south. The north-south width of the series, in the region of the Anaktuvuk, is about 30 miles, while its east-west extent is not known. It is probable that to the east it is soon delimited by the Anaktuvuk series, lying between it and the Paleozoics at the foot of the range. Westward, or rather northwestward, it may possibly extend to the Arctic coast, in the region between Point Barrow and Wainwright Inlet, but of this we have no paleontologic evidence.

Along Anaktuvuk River the topography of the Nanushuk series is of a character intermediate between that of the gently undulatory region of the Lower Cretaceous or Anaktuvuk series and that of the flat Tertiary coastal plain, whose terranes will be next described.

The rocks of the Nanushuk series are best exposed in the north bank of the Anaktuvuk about 5 miles above the mouth of Tuluga River. The exposure occurs in a bluff about three-eighths of a mile long that rises steeply 120 feet above the river (Pl. XII, *A*). The rocks, which here have a steep dip, are mainly thin bedded (Pl. XII, *B*). The beds range from 3 to 6 inches in thickness and exhibit rapid alternation. They consist of gray and brown sandstone, generally fine grained and sometimes friable, with some gray and impure fossiliferous limestone, dark shale, fine-grained gray quartzite, drab-colored and green chert, and black slate, stained reddish along the joints. Coal of good quality is also present (see analysis 107, p. 114). The beds strike N. 82° E., and dip south at an angle of 80°.

The above exposure seems to represent part of the south or upstream limb of an anticlinal fold which has been beveled off by erosion, for farther downstream the dip is north. Similar beds, probably belonging to the same series, were encountered, but not examined, about 10 or 12 miles above this point on the opposite side of the valley. Northward toward the Colville, where they are finally succeeded by the younger formation of the Tertiary coastal plain, the beds seem to lie more nearly horizontal. They possibly floor the valley and form the bed of Colville River down to about 5 miles below the mouth of the Anaktuvuk. Here are rapids which probably mark the termination of the series in the river bed, though the rocks are no longer exposed in the banks. Below this point the bed of the Colville appears to lie in the younger and softer formations of the coastal plain, and the current continues slack nearly all the way to the coast.

Structure.—So far as observed, the strike of the Nanushuk series is about east and west, and though, from comparison with some of the older rock series, we might expect the prevailing dip to be northward, observation has hardly been sufficient to affirm that it is so. The apparent existence of at least one pronounced anticline has been shown in the previous paragraph. The series is traversed by a system of approximately horizontal jointing (Pl. XII, *B*).

Age.—On paleontologic evidence the Nanushuk series is assigned to the Upper Cretaceous. The fossils were nearly all collected in the locality above described—on the north bank of the Anaktuvuk 5 miles above the mouth of the Tuluga. They have been identified by Dr. T. W. Stanton, who reports the lot to be certainly of Upper Cretaceous age. The forms identified are as follows:

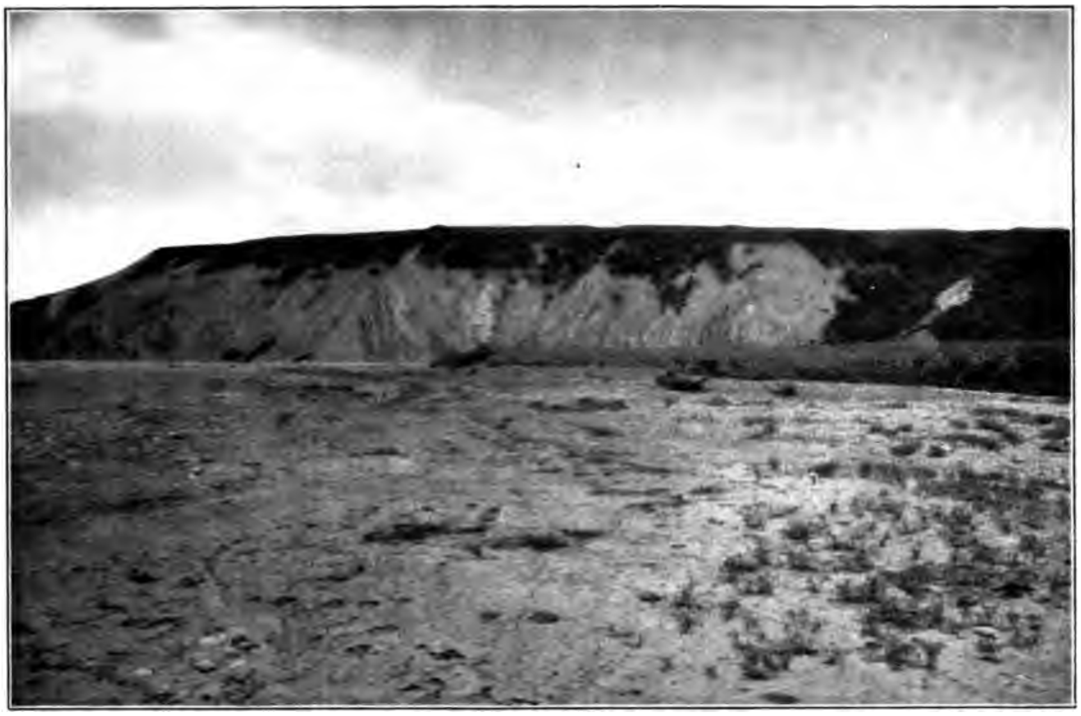
Fossils of the Nanushuk series from bank of Anaktuvuk River 5 miles above mouth of Tuluga River.

Inoceramus, a rather large species, fragmentary specimens.
A small Astarte, numerous specimens.
Nucula, numerous specimens.
Avicula.
Pectunculus, several specimens.
Thracia.
Tellina, 2 species.
Siliqua.
Modiola.
Scaphites.
Haminea.

Besides the above, there are casts and impressions of numerous bivalves not yet determined.

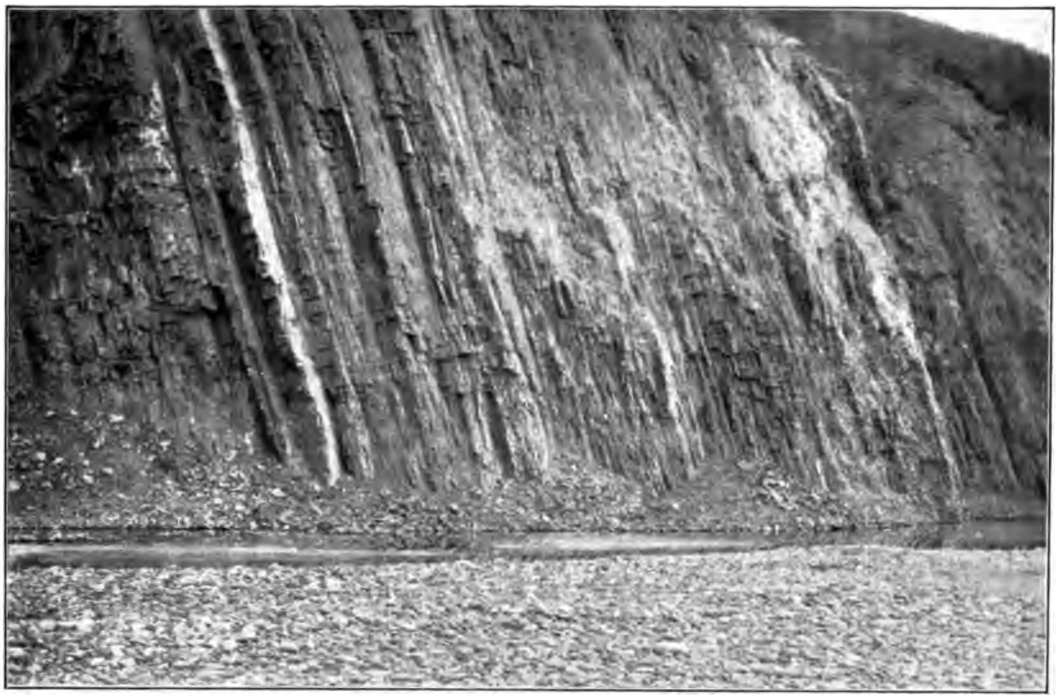
Concerning the above list, Doctor Stanton remarks that the species are all apparently different from those with which he is familiar, but that several of them are of types known only in the Upper Cretaceous.

Correlation.—Upper Cretaceous rocks occur also to the south of the Endicott Mountains in the Koyukuk and Yukon Basin, between the southern edge of the



A. BASE-LEVEL FEATURE IN NANUSHUK SERIES ON ANAKTUVUK RIVER.

Looking N. 30° E.



B. STRUCTURE AND RAPID ALTERNATION IN BEDDING IN NANUSHUK SERIES ON ANAKTUVUK RIVER.

Looking N. 70° E.

area here discussed and Nulato, and include, in part at least, the so-called Nulato sandstone. A description of this series was given in a previous report.[a] The fossils on which the assignment is made were collected by the writer in 1899 in the Nulato sandstone between Pickart's coal mine and Nulato, and are of interest as being the first Upper Cretaceous fossils found in Alaska. Of this collection, Doctor Stanton has reported the following forms, and refers the beds to about the same horizon as the early Chico of the Pacific region in the United States:

Upper Cretaceous fossils from the Yukon Basin.

Ostrea.
Anomia.
Mytilus.
Cardium.
Opis?
Lucina.
Trigonia cf. T. leana Gabb.
Corbula.
Actaeonella cf. A. oviformis Gabb.

East of the international boundary both Upper and Lower Cretaceous fossils have been found on the Porcupine by Mr. R. G. McConnell, of the Canadian geological survey.[b]

TERTIARY ROCKS.

COLVILLE SERIES (OLIGOCENE AND PLIOCENE).

Character and occurrence.—The Colville series is named from the large river along which it occurs and is excellently exposed. It is a series of Tertiary terranes which underlies the flat tundra country, or Arctic Coastal Plain, that succeeds the more southerly rolling plain formed by the Upper Cretaceous or Nanushuk series, which it apparently unconformably overlies, being itself in turn unconformably overlain by the Gubik sands. The strata which have been thus grouped extend along the Colville from some distance above the mouth of the Anaktuvuk nearly to the Arctic coast, occupying a belt 80 to 100 miles wide. Judging from the topography, the series probably has a very considerable extent in an east-west direction, possibly reaching the northwestern coast in the region of Point Barrow and farther southward. It also appears along the northern coast in places between Point Barrow and the mouth of the Colville, but has not been recognized.

The inland edge of the coastal plain, formed essentially by this series, has an elevation of about 800 feet, from which, with very gradual slope, the surface descends approximately to sea level at the coast. Beyond this, the very gradually deepening sea floor seems to be its continuation. Thus the subaerial tundra country and the submarine coastal shelf almost appear to be parts of the same plain. Beneath the sea, deposition is still active, while on most of the surface of the subaerial portion of the plain the work of erosion has hardly yet begun.

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[a] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900.

[b] Ann. Rept. Geol. and Nat. History Survey of Canada, vol. 4, 1888-1889, Montreal, 1890, pp. 122-125 D.

The series consists principally of heavy-bedded silts, soft sandstone, limestone, shale, and lignite. It is best exposed along the Colville in the region of the mouth of the Anaktuvuk, where it forms steep-faced bluffs about 200 feet in height, extending for a number of miles both up and down the river (Pl. VIII).

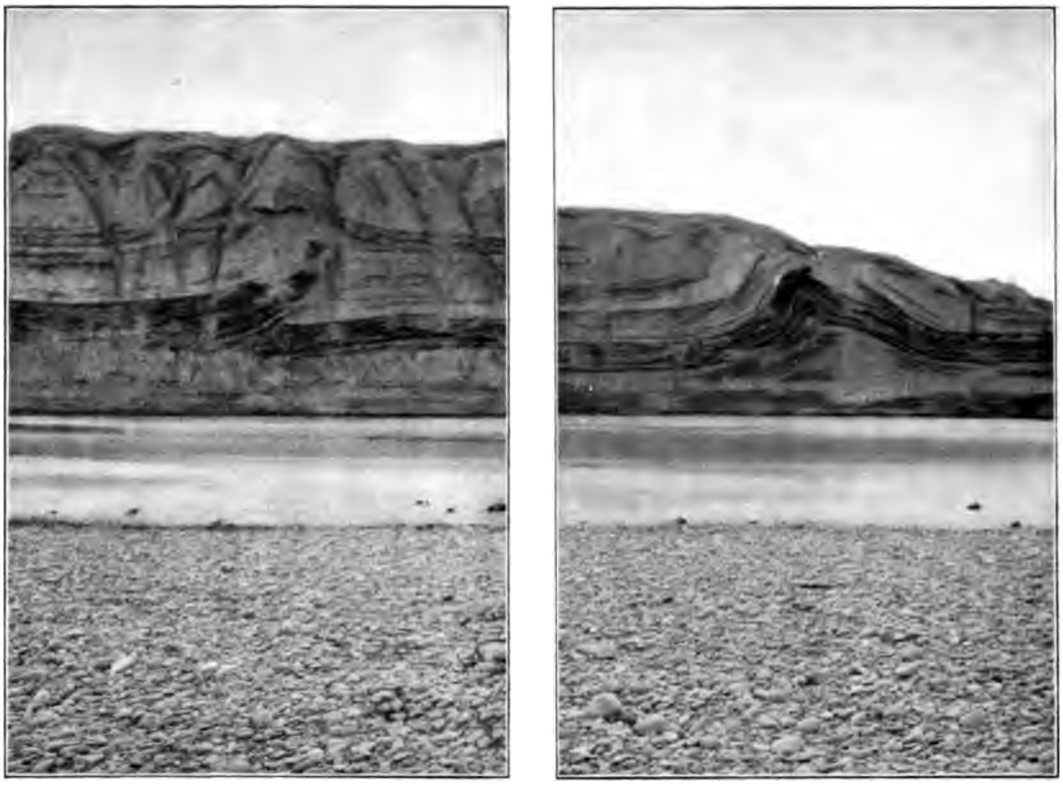
Structure.—The Colville series has been but little disturbed. The beds lie nearly horizontal. On the left bank of the Anaktuvuk, 10 or 12 miles above its mouth, they dip southward at an angle of 4° or 5°, but from near the mouth of the Anaktuvuk, along down the Colville nearly to the coast, they dip northward or northeastward (see Pl. VIII), so gently that great care is required to detect the introduction of successively newer and younger beds, as one ascends the geologic section in proceeding northward downstream. In the vicinity of the mouth of the Anaktuvuk some very broad, shallow depressions or folds are revealed. Above the mouth the dip is northward, at an angle of 8° to 10°, but a few miles below it is southward at about the same angle, so that the lower part of Anaktuvuk River seems to lie in a very shallow syncline.

Besides this gentle folding, the beds have also suffered slight faulting (see Pl. VIII, *B*). The maximum vertical throw in the faults observed is about 2 feet. Lateral crowding has also taken place, producing local crumpling or folds and small overthrusts, as shown in Pl. VIII, *B*, *C*, and Pl. XIII, *A*. In nearly all cases the crowding or thrust seems to have come from the south, indicating that crustal movements have apparently taken place in the mountain region in geologically recent time. The inland or upstream side of any particular stratum which has been broken or disturbed has been crowded or overthrust onto the coastal or downstream side of the same, often producing a short overlap. Disturbance, however, is hardly noticeable in the younger Pliocene portion of the beds toward the coast.

Observations made along Colville River indicate that the series has a thickness of 500 or 600 feet.

On account of difference in degree of consolidation of the beds, together with their fossil and lignite contents, the series has been separated by the writer into two parts, upper Colville and lower Colville. It is possible that an unconformity may exist between the lower and upper parts of the series, but if present it must be very slight.

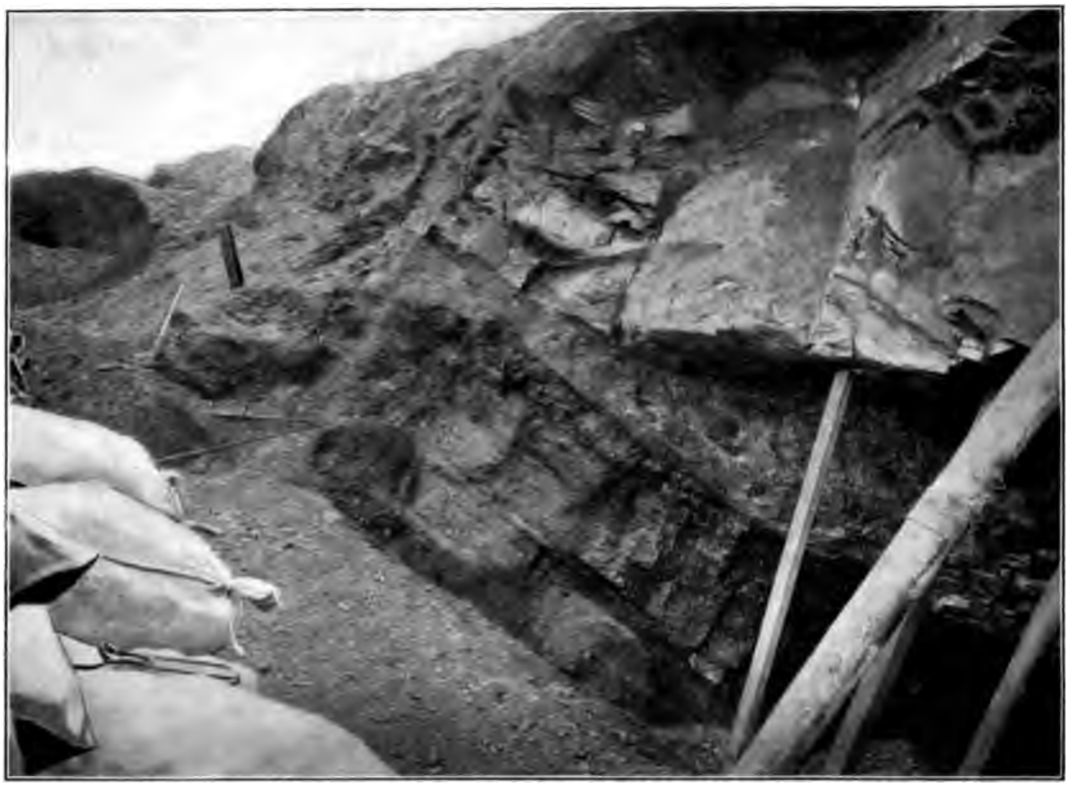
Lower Colville (*Oligocene*).—This constitutes the main portion or lower three-fourths of the section exposed at the mouth of the Anaktuvuk. It is about 150 feet thick, while the upper Colville at this same locality is about 40 to 50 feet thick.



A. *B.*

STRUCTURE IN COVILLE SERIES (TERTIARY).

A, Looking S. 50° W.; *B*, looking S. 65° W.



C. COAL BED AND ROCKS OF CORWIN SERIES AT CORWIN MINES.

Looking S. 45° E.

The lower Colville contains the more indurated class of rocks and consists mainly of partially consolidated silts in beds 6 to 8 feet in thickness. They are usually light slate-colored or ash-colored, and constitute about one-half of the lower Colville section, and are generally much less consolidated toward the top than near the base. The harder rocks, which increase in volume toward the base of the section, include impure, dull gray, medium to fine grained sandstone with detrital lignitic plant remains; slate-colored and brownish calcareous shale, with disseminated undeterminable vegetable detritus; lignitic coal in layers 1 to 5 feet in thickness; dark slate-colored or brownish chert, containing cavities incrusted with chalcedonic silica; rusty brown, very ferruginous sandstone or impure iron stone, and some iron-stained siliceous conglomerate, which also contains lignitic vegetable remains. There are also a few layers of hardened silts, forming a rock of very fine texture, resembling soft, smooth hone stone.

The lower Colvillé is tentatively classed as Oligocene, on account of the presence in it of lignite beds and vegetable remains, and from its resemblance to the Kenai beds occurring elsewhere in Alaska, and also on the ground of its relation to the supposed Pliocene silts which it immediately underlies. Several specimens of the shale collected from it, bearing lignitic plant remains, were examined by Doctor Dall, who reports that "the vegetable fragments are probably the needles of *Sequoia langsdorffii* Heer. These beds containing vegetable remains in northern Alaska are usually Upper Oligocene."

Upper Colville (*Pliocene*).—This portion of the section is practically free from indurated rock. It consists of nearly horizontally stratified beds of fine gray, slate-colored, or ash-colored calcareous silts, containing faunal remains. It is tentatively assigned to the Pliocene on the basis of fossils collected in place by the writer in the bluff (near its top) on the west side of the Colville about a mile north of the seventieth parallel (Pl. XIV, *A*). These have been reported on by Doctor Dall as follows:

Fossils from upper Colville series in bluff on west side of Colville River 1 mile north of seventieth parallel.

Chrysodomus, 2 species, both undescribed and very interesting; the first Tertiary arctic shells (not Quaternary) I have ever seen. Perhaps they are Pliocene.

Amauropsis sp., fragments.
Tachyrhynchus polaris Beck.
Macoma frigida Hanley.
Macoma incongrua von Martens.
Astarte semisulcata Leach (possibly Quaternary intrusion).
Saxicava arctica L.

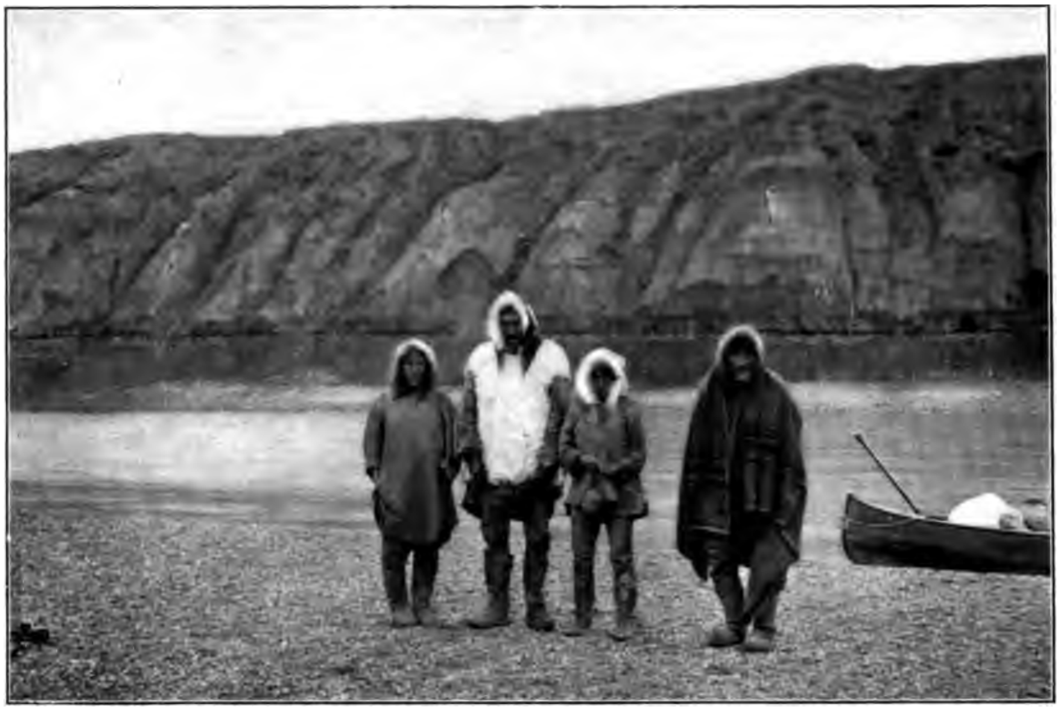
PLEISTOCENE DEPOSITS.

GLACIAL DEPOSITS AND GLACIATION.

Glaciation in geologically recent time in northern Alaska has not been of a continental character comparable to that of the northern United States and of the Cordilleran glacier, which overspread the vast field of the Pacific coast mountains in southern Alaska between the Yukon and the coast. It has been far more extensive, however, than has generally been supposed. In the valleys nearly everywhere within the Endicott Range evidence of ice action is shown by bed-rock scorings, local roches moutonnées, terminal moraines, and deposits of till on the lower valley slopes and benches. It has modified preexisting topographic forms, both by erosion of the rocks and by deposition of drift. In some cases, as revealed in places by erosion of the glacial deposits, steep-faced bed-rock benches in the sides of the valleys were covered and concealed by the drift, whose surface slopes gently down from the steep mountain side a distance of one-half mile or more, nearly to the present stream (Pl. XIV, *B*).

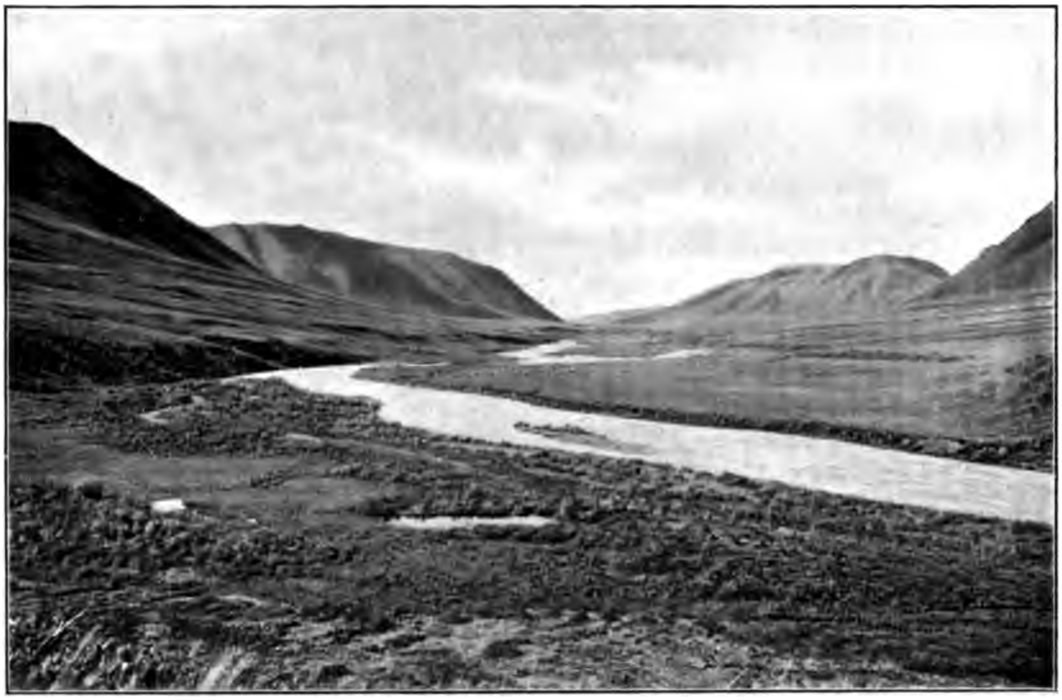
In the lower part of the intramontane section of John River, where the valley occasionally widens, it is sometimes floored by a till sheet, from 50 to 100 feet thick, containing ponds and lakelets, some of which seem distinctly to be of glacial origin. Till is prominent also in the mouths of some of the side valleys, as Till Creek Valley, which opens into that of John River on the east at about the sixty-eighth parallel. Here good exposures show the deposit to be typical till. It has a thickness of at least 100 feet, and forms a broad terrace or sort of small, triangular plateau a mile or more in extent, occupying the mouth of the side valley. It slopes westward, to where John River has been crowded to the bluffs on that side of the valley. On the east it overspreads and conceals the lower benching and bed-rock topography. Till Creek, a torrential stream, flows in a small canyon whose steep banks are formed of the bowlder clay or ground moraine.

In the region of Fork Peak, near the head of John River, at the confluence of several of its tributaries, the valley is wide and open and is floored by a till sheet at least 150 feet in thickness. The surface declines to the southwest, denoting that the deposit has largely come from the northeast, a view which is supported by bed-rock striæ farther down the valley. The till ascends the northwest slope of Fork Peak to an elevation of 2,500 feet, and may continue much higher, but becomes obscured by younger talus and coarse débris of doubtful character, which, however, also exhibits an ill-defined terminal moraine topography. At the elevation of about 3,500 feet is a bench overlain by talus and drift, which, judging from topography, was probably largely deposited by a local hanging glacier.



A. PLIOCENE FOSSIL LOCALITY IN COLVILLE RIVER BLUFFS (COLVILLE SERIES), TERTIARY COASTAL PLAIN.

Latitude 70° 1′; looking N. 25° W. Native Eskimo family in foreground.



B. GLACIATION IN UPPER JOHN RIVER VALLEY, IN ENDICOTT MOUNTAINS.

Looking S. 25° W.

The John Valley till sheet extends across the divide by way of Anaktuvuk Pass and is continuous with that of the Anaktuvuk Valley and the Arctic slope. At the pass the valley is 3 miles wide and open, and its surface is so flattened with infilled drift that the small streams descending from the mountains in this locality are deflected by the merest obstacle to either side of the divide, flowing sometimes northward by way of the Anaktuvuk to the Arctic, and at others southward to John River and the Yukon.

At the pass occur lakelets of glacial origin. One of these, Cache Lake (Pl. X, *B*), just northeast of the divide, is 30 feet or more deep. Its surface lies about 100 feet below that of the adjacent ground moraine, giving for the till sheet here a thickness of at least 130 feet. Just south of the pass the till sheet formerly extended entirely across the valley, as is shown by the flat-topped outlying remnants of ground moraine in its middle. These rise to the height of more than 100 feet above the stream, and accord in level with the ground-moraine terraces on either side.

On the whole, the till sheet in this northern part of the range seems rarely to extend up the side slopes to more than 500 or 600 feet above the floor of the valley. Judging, however, from the rounded and sometimes relatively flat-topped aspect of the mountains near the middle of the range (Pls. XIV, *B*, and XV, *A*), certain areas were not only occupied by an ice cap, but the tops of some of the lower mountains were planed off by ice movement.

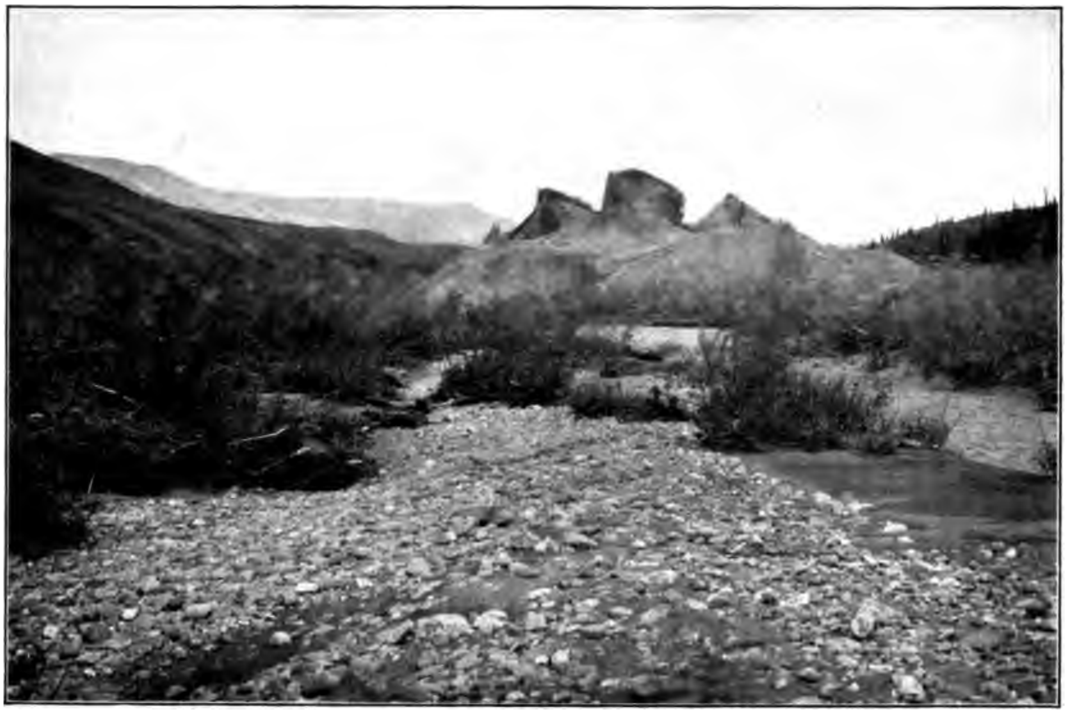
Naturally, the side valleys in this region were among the last to become free from glaciers, some of which probably remained long after the disappearance of the ice from the adjacent parts of main valleys. This is shown by the presence of relatively fresh terminal moraines in the side valleys. Four miles northwest of the middle of John River Valley the small valley of Contact Creek is crossed by such a moraine. It is typical, being about 60 feet high and one-fourth of a mile in length, measured parallel with the valley. A similar but older feature occurs in John River Valley, near the middle of the range, about 12 miles in direct line south of the sixty-eighth parallel. Here the valley flat is crossed by a terminal moraine about 60 feet high, a portion of which is shown in Pl. XV, *B*. It still forms a continuous ridge or dam across the valley, except where the river has cut a notch-like passage, 200 yards wide, at the left. At the right the moraine seems to be continuous with the till sheet, which is 10 to 20 feet thick, and rests on the bed-rock benching at a height of about 100 feet above the river. As seen in looking parallel with the valley, the ridge presents an undulating profile and is sharp-crested, owing to its upstream side being cut away by the river. Though it exhibits but little of the typical hummock-and-kettle topography of a terminal moraine, it is composed mainly of typical bowlder clay carrying striated pebbles and bowlders, some a foot or more in diameter. The materials noted are of the same constitution as those of the river gravels, there being no erratics. The principal surface or front of the moraine, which slopes southward, supports a growth of spruce, some of the trees having a basal thickness of 1½ feet.

A few miles above this moraine occurs the last lingering remnant of the John Valley Glacier. It consists of a lone, roughly circular mass of ice about 300 feet in diameter, rising from the middle of the gravel-covered valley flats to a height of 60 feet, as shown in Pl. XV, *A*. At the top the ice terminates in several distinct knoblike prominences, projecting 10 to 20 feet above the main mass. One of these is cylindrical or pipe shaped. The others are crudely pyramidal. The ice is partially capped and flanked by a deposit of genuine till from one to several feet thick, to whose protection it doubtless in large measure owes its preservation. From three sides small streamlets of light-colored muddy water, arising from the melting of the ice and thickened with glacial rock flour from the till, flow down and deposit their load of fine, argillaceous sediment over the flats around the foot of the mass. This glacial mud is of very light color. It is sticky, and differs decidedly from the present stream deposits of the valley. This ice mass is undoubtedly a remnant of the John Valley Glacier. Its presence at this late date, after apparently all the other glacial ice has disappeared from the surrounding region, together with the rounded topography of the adjacent mountains, already noted (Pl. XV, *A*), suggests that this locality is probably near what was the belt of maximum precipitation, and consequently of maximum ice accumulation, that traversed the mountains during Glacial time, and is therefore among the last to become free from ice.

In the north slope of Anaktuvuk Pass, between John and Anaktuvuk rivers, the till topography is locally rough and in part terminal morainic. North of Cache Lake it contains occasional stretches of distinctly termino-lateral moraine, trending toward Anaktuvuk River, and for the last 10 or 12 miles of its course, before leaving the mountains, the Anaktuvuk meanders sluggishly through a belt of flats one-half mile or more in width, which lie about 100 feet below the surface of the till sheet or ground moraine on either side. This till sheet, with a slope that rises gently in the main, but which is sometimes terraced, extends from the edge of the flats to the base of the mountains, 1½ miles distant. Near the flats the topography is often of a morainic type, being composed of characteristic hummocks and kettles, and undoubtedly represents a lateral moraine, deposited along the edges of the valley glacier that occupied the flats toward the close of Glacial time.

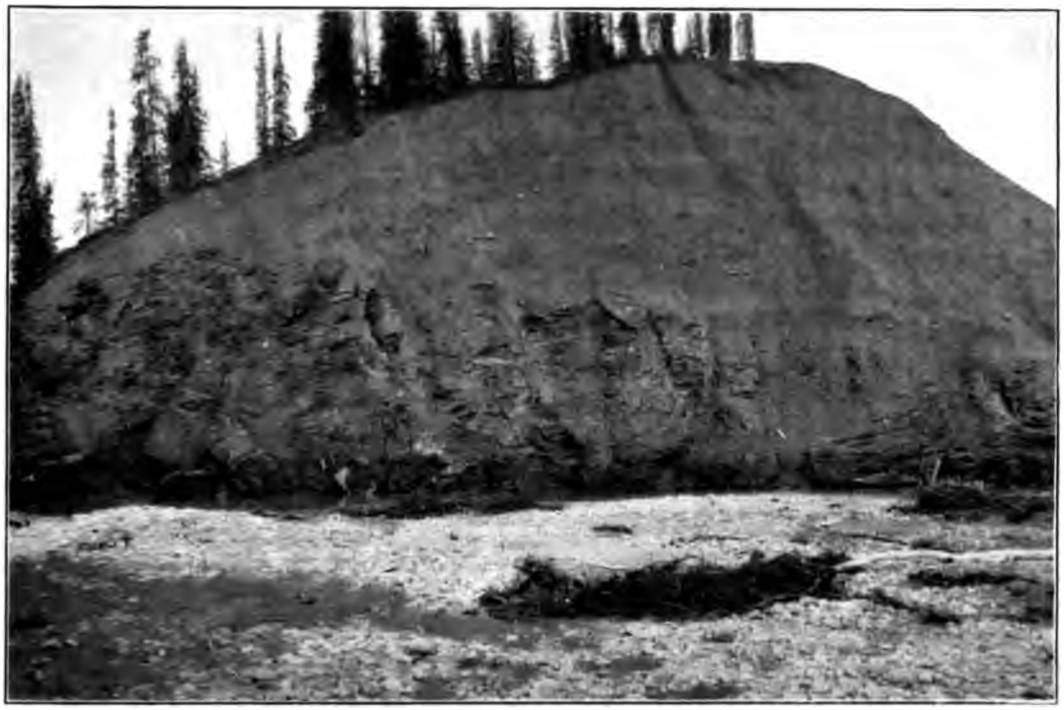
The height to which the drift, as a sheet, rises along the northern edge of the mountains away from the Anaktuvuk Valley was not determined. Judging from distant observations, however, it in some cases probably ascends the valleys to 800 to 1,000 feet above the general level of the Anaktuvuk Plateau.

As Anaktuvuk River leaves the mountains its current becomes less sluggish and its channel is soon beset with glacial bowlders. At about 4½ miles from the edge



A. ICE REMNANT OF JOHN VALLEY GLACIER IN ENDICOTT MOUNTAINS.

Looking southwest.



B. TIMBERED TERMINAL MORAINE RESTING ON FICKETT SERIES ON JOHN RIVER.

Looking southwest.

if by ice action, but the evidence as to the agency is not conclusive. On descending the slope northwestward, however, toward the Anaktuvuk, erratics of the Stuver conglomerate were found at an elevation of about 1,650 feet. The surface in this locality, however, is so densely covered with moss that drift may extend above this elevation and yet not be exposed. But on the whole, from this point northward, the till seems rapidly to become restricted to the lower side slopes of the valley, where it forms low bluffs and terraces.

About 14 miles below Willow Creek, near camp August 5, bluffs of probable till, resting against the bed-rock sides of the valley, rise to a height of 125 feet above the valley flats, and there, apparently as a thin veneer, the deposit overspreads the adjacent bed-rock bench. This bench is half a mile or more in width, nearly flat topped, and densely covered with vegetation, so that away from its river edge no satisfactory examination of the deposit could be made. A few hundred feet above the upper or distal edge of the bench, however, are outcrops of sandstone, presenting no drift or indication of ice action.

Twelve miles north of the above locality, about five miles above the mouth of Tuluga River (see Pl. XII, *A*), a similar bench, lying at 100 feet above the river, is capped by a deposit of gravel and sand 20 feet in thickness. Some of the pebbles approach the size of bowlderets, and even bowlders. Though they are waterworn, no stratification is apparent in the deposit, which has much the aspect of a sandy till. Its position suggests that it may have been deposited here by waters from the glacier that possibly occupied the valley at this point. The deposit may, however, be fluviatile.

Sixteen miles farther down the Anaktuvuk, about 10 miles above its mouth, the bluff on the left is again capped by from 10 to 40 feet of sand and gravel, in which the gravel is more distinctly washed and rounded than in the deposit above noted, but the absence of stratification and the character of the material again suggest that glacial waters may possibly have been an agency in its deposition. If this inference is correct, the ice stream which occupied the Anaktuvuk valley must have extended down nearly to this point. There is, however, no reason to suppose that it extended below it. On the adjacent part of Colville River there seems to be no evidence of glaciation within a score or more miles above the mouth of the Anaktuvuk. The drainage of this section of the Colville does not seem to have been interrupted since the Tertiary.

From the conditions above described it is concluded that in the region of the Anaktuvuk Valley, in that portion of the Colville Basin embraced by the curving front of the Endicott Mountains, an ice sheet in the form of a small regional or piedmont glacier, gradually thinning out toward the north, extended from the front of the range northward across the inner part of the Anaktuvuk Plateau to the region of Willow Creek, a distance of 30 or more miles. Beyond this point ice flowage seems to have been confined substantially to the present drainage ways, in the form of valley glaciers, of which that of the Anaktuvuk is the chief.

There is evidence that the Anaktuvuk glacier extended northward to the sixty-ninth parallel, and there are some indications that it may possibly have extended 30 miles farther, to within 10 or 12 miles of the present mouth of Anaktuvuk River, but it is not to be supposed that it crossed Colville River, if indeed it ever reached it. This latter statement is probably also true of the ice streams to the west that must have occupied the valleys of Ninuluk, Killik, Kurupa, and Kucher creeks, which enter the Colville a little north of the sixty-ninth parallel.

It does not seem probable that the drift sheet on the Arctic slope much exceeds 150 feet in thickness at any point. It apparently attains its maximum development in the valleys, not far from the mountains, the source of supply. Elsewhere on the slopes its surface seems to conform very largely to the preexisting topography of the underlying terranes.

In the southern part of the Endicott Mountains, evidence of glaciation, as has been shown, may be found up to an elevation of nearly 2,000 feet. From the point where John River leaves the mountains, southward to the region of Kanuti River, the Koyukuk Valley region exhibits a generally rounded topography, which suggests former glaciation, up to a height of 1,600 or 1,800 feet. On John River, near the base of the mountains, the drift, so far as observed, is essentially till. In some localities the deposit is at least 100 feet thick, and is marked by several terraces that rise successively from the river to the southeast, above which the surface continues to have a rolling, apparently ground-moraine topography, that finally gives way to low, rounded mountains or hills, which also are supposed to be glaciated.

Observations in the above region away from the immediate route of travel were very limited. Along the route, however, glacial drift seems to be more or less continuous all the way down the open flats of John River Valley, as is shown by the topography and by occasional exposures of till rising to a height of 30 or 40 feet above the river or resting in thinner sheets on the bed-rock benches at elevations of from 30 to 100 feet above the stream.

Till is present near the mouth of John River and on the right or west bank of the Koyukuk between Bettles and the mouth of Jane Creek, where it forms bluffs about 100 feet high. Similar conditions seem to prevail to the eastward, in the region of Gold Bench[a] on South Fork, whence they apparently continue northeastward across the divide into the Chandlar River Basin, where till deposits similar to those on John River have been noted in a previous report, and have since been observed to extend up Granite Creek.[b]

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[a] When the only opportunity for making observations at Gold Bench was presented, 5 feet of snow lay on the ground.

[b] Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 478.

No glacial drift was noted on the top of Lookout Mountain, and, as the surface was deeply snow covered at the time it was visited, the elevation to which the drift ascends on its slope could not be learned. Southward, on the northeast side of the lower Alatna Valley, what seem to be till terraces occur along the south side of Double Mountain up to a height of 1,600 feet.

Just below the mouth of the Alatna the right bank of the Koyukuk presents a steep-faced exposure of clay and gravel, rising 80 to 100 feet above the river.[a] The lower 50 feet of this section seems to be till, and is distinctly separated by a well-defined contact from the upper portion, which consists mostly of gravels and silts, some of which are discordantly stratified.

From the character of the topography glacial drift is supposed also to occur on the opposite side of the Koyukuk and to extend southward toward the mouth of Kanuti River. Mr. Mendenhall reports that in the country lying north of this region, on the upper waters of the Alatna and the Kowak, above the sixty-seventh parallel there is evidence of glaciation similar to that in the same latitude on John River. Furthermore, in the recent gravels along the Koyukuk near Bergman, notably on the south side of the river, there are large granitoid bowlders, totally foreign to the country rock of the region. These may have been brought here through the agency of river ice from far up the valley of South Fork, but it seems equally probable that they may have been brought by glaciers from the mountains to the north where similar rocks in place are known to occur.

The hill just west of Bergman consists of Bergman sandstone, but on its slope, at a height of nearly 200 feet above the river, there is a gravel deposit composed of heterogeneous materials. An examination, as thorough as could be made under unfavorable conditions, indicates that ice action was concerned in its origin. It contains characteristically angular and subangular ice-worn pebbles, with polished surfaces, often profusely striated. The striæ are of distinctly glacial origin and can in no wise be ascribed to the action of river ice.

From the above-enumerated observations in this southern part of the field it is inferred that glaciation extended from the mountains southward into the Koyukuk Basin across the Arctic Circle and beyond Bergman, but observation has not been sufficient to determine whether this extension was in the form of a continuous ice sheet, or merely as valley glaciers. From topographic criteria, however, it seems probable that most of the hills below 2,000 feet were covered by ice or névé, while such peaks as Mount Lookout and its higher fellows appeared as nunataks above its surface, and that glacial activity, or ice work, was largely restricted to the valleys and lower reaches of the hill slopes.

In the John River and Anaktuvuk River portions of the Endicott Mountains the glacier ice (save the single instance cited on John River) has disappeared. To the east, however, as noted under "Previous explorations," prospectors and whalers who have crossed the range in the vicinity of the one hundred and forty-ninth meridian report the presence of valley glaciers of considerable size.

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[a] This bluff is the Unatlotly of the natives.

The glacial phenomena that have been described tend to show that, although the Endicott Mountains (Pl. VII) do not on the whole seem to have been overridden en masse by a moving ice sheet, they were doubtless, especially in their northern part, largely occupied by an ice cap or perennial névé, constituting a breeding ground for glaciers. The zone of maximum snowfall, and consequently of maximum ice accumulation, trending in an east-west direction, was apparently in the northern part of the range at least somewhat north of its median line. From this zone the ice moved off to the north and to the south, respectively, into the Colville and Koyukuk basins. Its flowage, especially during the latter part of the Ice age, was confined mainly to the valleys and drainageways in the form of alpine glaciers, of which there is ample evidence. But there is also good reason to believe, as shown by the till sheet north of the mountains, that during the zenith of the Ice age the northern edge of the range was occupied by a more or less extensive ice sheet, which, as a small regional or piedmont glacier, thinning out toward the north, extended northward over a considerable portion of the Anaktuvuk Plateau, its occurrence at that time being, perhaps, similar to that of the Bering or Malaspina glaciers of to-day.

GROUND-ICE FORMATION AND KOWAK CLAY.

At some localities along the Arctic coast there are stretches of low bluffs or banks of ground ice overlain by a deposit of dark muck and moss several feet in thickness. Deposits of light-colored clay also are occasionally seen. The occurrence and distribution of these deposits appear, in a measure, to be as represented by Doctor Dall on his map of the "Known distribution of the Neocene formations in Alaska."[a]

The ground-ice formation was hitherto supposed to be of very widespread occurrence in this Arctic region. To give an idea of the evidence on which this supposition rests I shall here freely quote from Doctor Dall's report.[b]

"From information gathered from several masters of vessels in the whaling fleet, and derived from experience gained in the effort to dig graves for seamen who had died aboard vessels on this shore from time to time during the last twenty years, it would appear that somewhat north of Cape Beaufort the land between the low hills and the sea is low and the soil chiefly a sort of gravel. 'At a depth of 2 feet is a stratum of pure ice (not frozen soil) of unknown depth. This formation extends, with occasional gaps, north to Point Barrow, and thence east to Return Reef, where the ice layer is about 6 feet above the level of the sea. It goes south at least as far as Icy Cape without any decided break, and is found in different localities as far south as Kotzebue Sound.' At Point Barrow, near the international station, under the direction of Lieut. P. H. Ray, U. S. Army, a shaft was sunk to a depth of 37 feet 6 inches, which passed through successive layers of mud, sand, and fine gravel, with fragments of driftwood and marine shells, showing here and there large fragments of pure fresh-water ice, but no continuous stratum of ice. The formation here was clearly a beach alluvium, and relatively modern, a pair of Eskimo wooden snow goggles with sinew string still attached to them being found at a depth of 27½ feet. The temperature of the earth varied from −5° to +17.5° F.; below the influence of the external air the temperature of the earth was quite steady at 12° F. for nine months. The earth was frozen and was extremely hard and tough. Blasts put into the side of the shaft blew out without shattering the frozen earth around the drill hole. It is probable that excavations farther inland might have revealed the ice layer, which at the locality of the station did not exist."

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[a] Dall, W. H., Correlation papers, Neocene: Bull. U. S. Geol. Survey No. 84, 1892, opposite p. 268. Becker, G. F., Reconnaissance of the gold fields of southern Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pl. 1.

[b] Op. cit., p. 264.

The observations made by the writer, while boating along the coast, lead to the inference that the ground ice is not of so widespread occurrence as the above quotation indicates. Between the Colville and Point Barrow the ice is possibly more or less continuous along the coast, but of its inland extension we have little evidence. Even along the coast it is not extensively exposed. Here long stretches of the low tundra country are apparently underlain by rock or earthy deposit.

Of the localities at which the ice was observed, the most important are Cape Halkett and Cape Simpson, at each of which it seems to be practically continuous for a distance of several miles. Cape Halkett, one of the most prominent promontories along this part of the coast (Pl. X, *D*), terminates in an ice cliff rising 30 feet above tide level, and is overlain by a foot or two of muck, which in turn is carpeted by a nap of moss and grass at the surface. Judging from topography, the ice at this locality may extend inland several miles. Its thickness is not known, since its lower limit lies below tide level. As shown in the view (Pl. X, *D*), the cape is being rapidly cut back by wave action, which undermines the cliff at tide level until by its own weight the ice breaks off in large blocks and is ground up by the surf.

Coal occurs at Wainwright Inlet, between Point Barrow and Cape Beaufort. A little southwest of that place the Jura-Cretaceous comes to the coast, and, judging from topography, seems to continue nearly all the way to Cape Beaufort, omitting a probable breach at Icy Cape. From Cape Beaufort to Cape Lisburne rocks of the Corwin series (Mesozoic) are known to be almost continuous. It therefore seems, from the above facts, that the southern boundary of the ground-ice area represented on Doctor Dall's map should be shifted from the region of Icy Cape northward, probably to at least beyond Wainwright Inlet, a distance of 60 to 75 miles.

Of the Kowak clay containing Pleistocene vertebrate remains, referred to by Doctor Dall in connection with the ground ice, but little was seen by the writer. Observation, however, has been sufficient to suggest that, if present along the coast

RECENT MUD, MUCK, GROUND ICE, DUNE SAND, SILTS, AND GRAVELS.

INLAND REGION.

The deposits mentioned in this heading are all represented on the map by the same color.

Along John River and the Koyukuk the color represents recent stream gravels, together with alluvial sands, silt with ground ice, mud flats, and areas of till too small to be represented on the scale of the accompanying map.

Along Anaktuvuk River the color denotes recent stream gravels, while along Colville River it includes, besides the recent stream gravels, a large, triangular area of flats extending from the mouth of the Anaktuvuk to the coast and eastward along the coast a distance of thirty or more miles to beyond Gwydyr Bay. This large area, as noted, is regarded as ground abandoned by the Colville in its lateral migration westward since Tertiary time, as the river is supposed to have formerly flowed more directly northeastward from the mouth of the Anaktuvuk, and to have entered the sea through Gwydyr Bay, following the course indicated by the broken lines on the map. (Pl. III.)

Though to the eye this area of flats seems a dead level the surface probably rises very gently from the Colville eastward. It is dotted by numerous ponds and lakelets. The monotony of the waste is somewhat relieved by occasional low mounds, as shown in Pl. XVI, *B*. These are composed, in part at least, of gravel and sand. Some of them rise as much as 40 feet above the flats. In shape they are low and rounded. Some have a tapering train on the lee side toward the coast. Their surface is usually scantily clothed with grass and other vegetation.

The origin of the mounds is not known. Only one of them was visited. Perhaps the most plausible hypothesis is that they are remnants of beds belonging to the Tertiary Colville series, which, chancing to be capped with some hard stratum, were not worn down by the river to the level of the flats, and so formed nuclei favorable for accumulation of gravel, and subsequently became bars, and, later still, islands in the Colville, until the river abandoned its bed about their bases.

Along the Colville the edge of the flats often terminates in gravel bars, descending to the water's edge, or in low, steep-faced banks of frozen black muck and ground ice, showing that at least the surficial portion of the flats consists in the main of recent stream deposits and the decayed products of marsh vegetation. The banks decrease in height toward the coast, and finally vanish as the land surface passes into the bars, reefs, and tidal mud flats at sea level.

The geologic work now being done by the river in its lateral migration shows that the processes by which the flats were formed were essentially those of planation. In the inland region, as the shifting stream, in its very gradual down-cutting and relatively very rapid lateral cutting, sawed its way westward into the coastal plain, it planated farther and farther on the west the ground which by its destructional work it claimed as its bed; while simultaneously, as it abandoned or receded from this planated ground on the east, it built thereon, notably at high-water stages, flood-plain and riparian deposits, which now constitute the surficial terrane of the flats. Thus, while degradation or destructional work was in progress on the west, aggradation or constructional work of flood-plain building was progressing on the east. At the same time in the coastal region the large amount of sediments borne down by the river was built into an expansive delta plain, which landward merges into and is continuous with the inland subareal portion of the flats, and seaward merges into the already mentioned expansive tidal mud flats, bars, and reefs at the coast.

The Colville Flats therefore appear to consist essentially of a Pleistocene veneer of flood-plain, ground-ice, and deltoid deposits resting on Tertiary beds of the Colville series that have been planated by the river in its lateral migration toward the west.

Another type of recent deposits is seen in the sand dunes that occur for a distance of a few miles along the upper part of the Anaktuvuk, just before it leaves the Endicott Mountains, and also over the inland portion of the Colville delta and adjacent mainland. The material of the dunes in both places is obviously river sand and silts derived from the wind-swept bars and flats exposed during stages of low water. This dune work is probably accomplished mostly during the dry, frozen periods of winter, when the bare ice surface is favorable for wind transportation of the material.

COASTAL REGION.

From Colville River to Point Barrow.—Though the Tertiary beds of the Colville series may come to the Arctic coast in some localities, they have not been positively identified there. From Colville River to Point Barrow the shore line materials consist mainly of recent beach deposits of mud, muck, some sand and gravel, and deltoid mud flats, backed in places by low banks of older dark muck and ground ice (see Pl. IX, *A* and Pl. X, *D*). West of the Colville, in Harrison Bay, deposits of sand or loam are occasionally seen, which, from similarity in character of material, seem to belong to the Gubik sand.

The eastward swing, or retreat, of Colville River in relatively recent time from bluffs of its own cutting on the west, leaving a portion of the Colville Flats on its west or left side, along the section extending from Ocean Point to the coast, a distance of nearly 40 miles, suggests for this particular part of the region a local tilt to the eastward in Pleistocene time, or at least subsequent to the production of the bluffs and the Colville Flats, which must have been formed by the river. If this tilt or differential uplift to the west of the Colville has been far-reaching in its westward extent, it favors the existence of a coastal belt of late Pleistocene as far as it extends.

To local differentials in elevation along this costal line of uplift are to be ascribed the occasional ground-ice cliffs as at Cape Halkett and Cape Simpson, alternating with long stretches of low shelving beach. The ice cliffs appear merely to represent completely solidified bays, lagoons, lakelets, or perhaps other coastal bodies of ponded water now raised into low anticlines and cut back by wave action.

From Point Barrow to Cape Lisburne.—Southwest of Point Barrow the coast line grows more marked. It is not so low, flat, and shelving as on the north, and the water is consequently less shoal. Here the long stretches of mud flats found on the north are in the main wanting. The mainland bluffs at the edge of the tundra, though still low, are not only higher than on the north but are almost continuous, and are frequently composed of true bed rock (Mesozoic terranes); between the base of these bluffs and tide water there is a narrow fringe of recent beach gravels and sand, whose surface slopes steeply seaward. However, from Wainwright Inlet to near Cape Beaufort there are extensive wave-built barrier beaches or bars of recent marine gravels and sand (see Pl. XVI, *A*), sheltering immense stretches of brackish lagoons lying between the bars and the mainland. Toward Cape Lisburne, the most bold and important promontory in this part of the northwest, the coast becomes steep and rock bound (Pl. V) by the Mesozoics and Paleozoics that have been described.

RECENT FOSSILS FROM THE ARCTIC COAST.

The following invertebrate fossils were collected along the Arctic coast between Colville River and Cape Lisburne. The identifications are by Dr. W. H. Dall, of the United States Geological Survey.

Chrysodomus fornicatus Gray, 649,[a] 650, 654.
C. despectus L., 639.
Admete couthouyi Jay, 652.
Margarites striatus Sowerby, 647.
Tellina lutea Gray, 647.
Macoma frigida Hanley, 636, 639, 647, 650.
M. tenuis Leach, 639, 652.
M. baltica var. inconspicua B. & S., 636.
Astarte arctica Gray, 636, 639.
A. borealis Schumacher, 636, 639, 650, 652, 654.
Venericardia alaskana Dall, 652.
Saxicava arctica L., 650.
Serripes grönlandicus Beck, 636, 654.
Cyrtodaria kürriana (Mörch) Dunker, 639, 650.
Thracia beringi Dall, 654.
Mytilus edulis L., 650.
Modiolaria nigra Gray, 650.
Yoldia sp. fragm., 639.

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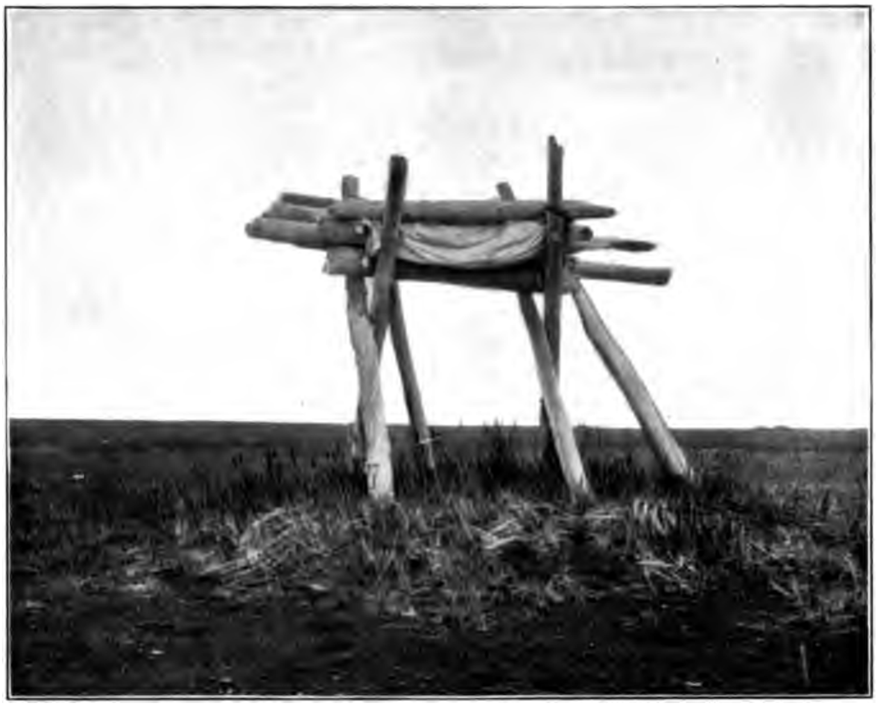
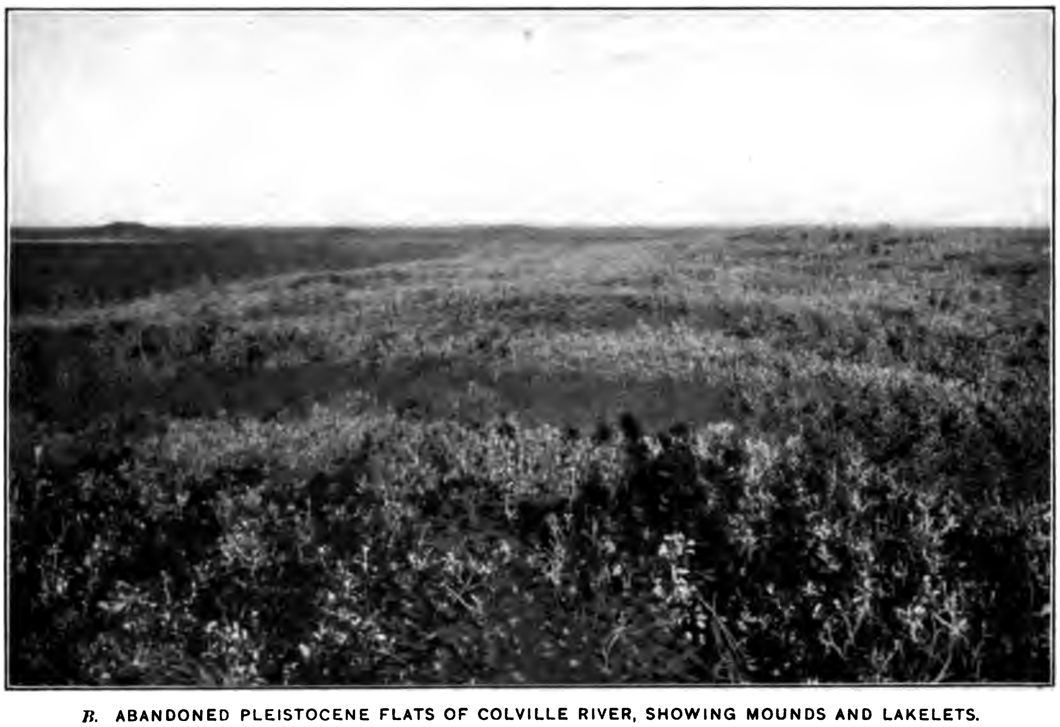
[a] The numbers refer to localities.



A. BARRIER REEF AND ESKIMO GRAVE ON ARCTIC COAST NEAR ICY CAPE.

Looking S. 25° W.



B. ABANDONED PLEISTOCENE FLATS OF COLVILLE RIVER, SHOWING MOUNDS AND LAKELETS.

From 30 miles inland; looking N. 80° E.

TABLE OF PROVISIONAL CORRELATIONS.

			Schrader: Chandlar and Koyukuk rivers, 1899.[a]	Mendenhall: Dall, Kanuti, Alatna, and Kowak rivers and Kotzebue Sound, 1901.[b]	Schrader: Chandlar, Koyukuk, John, Anaktuvuk, and Colville rivers and Arctic coast from Colville River via Point Barrow to near Cape Lisburne, 1901.
	Pleistocene		Stream silts and gravels	Silts, clays, sands, and gravels, including glacial deposits, Kowak clays and ground-ice formation.	Stream and beach gravels, mud (flats), sands, and silts.
			Till and glacial gravels.		
			Lacustrine silts of Yukon and Koyukuk flats.		Dune sands. Gubik sand. Till and glacial gravels.
			Ground ice and Kowak (?) clays.		Ground ice and Kowak clay.
	Tertiary	Pliocene	Basalts of Koyukuk Mountain and Chandlar River.	Basalts, andesites, and andesitic breccias.	Upper Colville.
		Miocene	Nulato sandstone ?.		
		Oligocene			Lower Colville.
		Eocene	Kenai series ?	Kenai series.	
Mesozoic	Cretaceous	Upper	In Koyukuk Basin and in Nulato sandstone ?.	Bergman series	Nanushuk series. Bergman series (?).
		Lower	In Koyukuk Basin, including igneous rocks.		Koyukuk series, including igneous rocks. Anaktuvuk series.
	Jura-Cretaceous				
	Jurassic				Corwin series.
	Triassic				
Paleozoic	Carboniferous	Upper.			
		Middle.			
		Lower	West Fork series (?)		Fickett series.
	Devonian	Upper		Kanuti series.	
		Middle	Bettles series		Lisburne formation.
		Lower		Metamorphic complex.	
	Silurian	Upper	Lake quartz-schist		Stuver series. Totsen series. Skajit formation.
		Lower	Amphibolite-schist.		
	Pre-Silurian		Chandlar Rapids schist. Gneissoid granite, basalt (?).		

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[a] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 471–482.

[b] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers: Prof. Paper U. S. Geol. Survey No. 10, 1902, pp. 31–48.

MINERAL RESOURCES.

GENERAL STATEMENT.

Under the head of geology, it has been shown that the rocks forming the mountains about the head of the Koyukuk Basin comprise several metamorphic series, namely, the Skajit, Totsen, Fickett, Bettles, Lake quartz-schist, and West Fork series. In these mineralization has taken place. It is in the southern part of the region that the efforts of the prospector are being rewarded, and, in some cases, handsomely.

Though indications of mineralization occur to some extent nearly all the way northward through the Endicott Mountains, the principal producing region is on the upper parts of Middle and North forks of the Koyukuk. Though the region also contains coal and some lead, copper, and antimony, thus far gold only has proved to be of economic importance.

GOLD.

Placer gold has been known in the Koyukuk Basin since the early nineties, if not before. It was first discovered in the bars of the river, of which the most noted seem to have been Hughes and Florence bars, both far below the present placer diggings. Tramway Bar, above the sixty-seventh parallel, about 570 miles above the mouth of the river, is among the earliest discoveries. The discovery of Slate, Myrtle, and the other creeks that have been among the chief producers for the last four years was made during and subsequent to the spring of 1899. These are mostly above Tramway Bar.

Roughly considered, the Koyukuk gold district, or gold diggings, frequently referred to as the most northern mining camp in the world, as known at present is contained in a rectangular area of about 3,500 square miles, lying between latitudes 66° 55′ and 67° 55′ and longitudes 149° 30′ and 151° 20′.[a] It accordingly trends north and south. Its length is about 70 miles and its width about 50 miles. Diagonally through it from northeast to southwest flows Middle Fork of Koyukuk River, while the northwest portion is drained by North Fork and the southeast portion by South Fork. The principal field of present operations is near the middle of the district, on the middle drainages of Middle and North forks.

It is only in certain localities in this area, however, that profitable gold placers have been found. The formations on which these placers lie, so far as known, are the Lake quartz-schist, the West Fork schist, the Bergman series, and probably also the Skajit formation, for some of the later discoveries are reported to occur on mica-schist, limestone, and marble;[b] but whether any or all of these formations are the original source or mother rock of the gold can not yet definitely be stated, as the season's work afforded no facility for visiting the diggings. The Slate Creek gold, however, is probably derived from the Lake quartz-schist.[a] These schists are traversed by quartz veins of considerable size, the larger of which are not known to carry more than a trace of gold, but a series of smaller veins or veinlets and small lenticular quartz bodies or leaflets contained in the schist are to some extent auriferous. Nearly all quartz specimens which have been assayed show at least a trace of gold.

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[a] For location and outline of the district, see geologic map, Pl. III.

[b] On Clara and Emma creeks the country rock is reported to be mica-schist and marble.

The principal diggings when the region was visited by the writer in 1899 were those of Slate Creek and Myrtle Creek, which lie along the zone where the Lake quartzite-schist gives way to the West Fork[b] series on the south. This zone is also along the line where the mountains give way to the dissected supposed Yukon Plateau. Here in March, 1899, coarse placer gold was discovered in paying quantities on Slate Creek, an east side tributary of Middle Fork of the Koyukuk, which it joins 16 miles above Tramway Bar. The country rock is a series composed of mica-schist, quartz-schist, and slate, and is cut by some igneous intrusives. It is uplifted and stands on edge. The gold occurs as shallow creek and gulch diggings, and is found principally near or on bed rock in joints, fissures, and crevices. The gravels rarely exceed 3½ feet in thickness. The diggings begin about 9 miles above the mouth of Slate Creek, at the confluence of the two main forks, of which the north one is known as Myrtle Creek, and the south one as Slate Creek proper. From this point the diggings extend to the head of Myrtle Creek, a distance of 5 or 6 miles, and considerably farther up Slate Creek.

Two mining districts had been organized and are known as the Slate Creek and Myrtle Creek districts. The gold, as seen here, is bright, clean looking, coarse, and considerably rolled or flattened, denoting transportation. The largest nugget taken out had a value of nearly $20. The bench gravels along these creeks are also auriferous and are reported to prospect from 3 to 5 cents per pan. Considerable mining was also being done near the sixty-seventh parallel on various tributaries of South Fork with fair success; here at present the principal camp is that of Gold Bench.

Though the Slate and Myrtle creek districts, with a few others, are reported to have yielded well during the season of 1899 and 1900, and are still producing, subsequent exploitation has resulted in the discovery of much richer deposits farther up the river, all occurring, according to reports of the miners, in much the same class of metamorphic rocks as those noted for Slate and Myrtle creeks.

Of these newer discoveries, the principal are Emma, Clara, and Gold creeks, and other smaller streams tributary to Hammond Creek, while the discovery of gold on Union Gulch, about 15 miles above Slate Creek, is reported to have been made during the summer of 1901. Other new creeks, reported to be producing, are Vermont, Swift, and Nolan. The two best producers thus far are reported to be Emma and Gold creeks. The gravels on Hammond Creek are reported to contain much iron pyrites, which, in sluicing, rapidly fills up the riffles, and in some specimens visibly exhibits embedded bodies and particles of free gold—a fact of no small economic importance, as it seems to point very strongly to deposits of gold-bearing pyrites or ore probably present within the Hammond Creek Basin as the source of the gold. During the summer of 1902 very promising prospects were discovered also on North Fork of the Koyukuk about 35 miles above its mouth. Here the belt containing gold-bearing gravels, locally considered, is said to have a width of about 20 miles and to trend in a general east-west direction about parallel with the mountains. The principal streams on the Fork are Mascot, Washington, and Big Four creeks. The discovery was made on Washington Creek in August, but the principal producer seems to be Mascot, a west-side tributary, which was discovered in September (1902), and during the season of 1903 yielded nearly $100,000 in gold. This gold is coarse. It contains several $100 nuggets, and other large ones of less value. The gravels are shallow; they range from a few inches to several feet in thickness, and contain a little black sand. Their shallowness enables the ground to be worked at a profit of about 70 per cent of the yield, which is much greater than that in most of the creeks of the Koyukuk district. The gold is found mostly on bed rock and in the extreme basal part of the overlying gravels, and where the bed rock is rotten or decayed the gold frequently extends a foot or more into it. The bed rock is mica-schist. It contains stringers of quartz and is occasionally cut by porphyry dikes. Gold prospects have also been found west of the above, on tributaries of the Hokotena.

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[a] Schrader, F. C., Reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 474–483.

[b] Ibid., p. 475.

The Tramway Bar diggings are bench placers, consisting apparently of deposits of auriferous river gravels resting on a bench of bed-rock conglomerate and sandstone, at about 80 to 100 feet above the level of the river. The gravels are mostly coarse, consisting largely of rolled cobbles and pebbles of quartz-schist and other rocks composing the mountains to the north. Several attempts have been made to work these deposits, but thus far with only moderate success. This is owing apparently to the remoteness of the region, the difficulty of transportation, and more especially to the lack of capital to utilize the water supply, which could readily be drawn from the river above the placers or from lakelets said to occur on higher ground lying westward.

The Tramway conglomerate has not as yet been found to be a fossil placer, as was formerly supposed, nor does it seem to bear any relations to the richer diggings occuring in the region of metamorphic rocks much farther up the river.

Prospects of gold are also reported to have been found on some of the tributaries very little quartz being present. It presents a clean, bright surface and is of a deep, rich color. Another nugget, nearly as large as the above, having a weight of 50 ounces and valued at about $1,000, was found on Hammond Creek during the same year, but was not brought out of the country until this fall (1903). It is described by Mr. Prindle as oblong and elongated in outline, flat on one side and rounded on the other.

According to the most reliable information obtained, the production of the Koyukuk district from 1899 to 1903 was about $717,000, distributed among the various creeks and gulches, principally as follows:

Production of gold in the Koyukuk district from 1900 to 1903.

	1900.	1901.	1902.	1903.
Myrtle Creek	$40,000	$7,000		
Gold Bench	25,000	60,000		
Slate Creek	1,000?			
Emma Creek	27,000	40,000		
Clara Creek	1,000	2,000		
Gold Creek	2,000	50,000		
Tramway Bar	5,000			
Twelvemile Creek	1,000	1,500		
Porcupine Creek	500	1,000		
Ironside Bench and Eagle Bluff	1,000			
California Creek		1,000		
Union Gulch		1,500		
Total	103,500	164,000	[a]100,000	[b]300,000

[a] Season's yield, including new discoveries.

[b] Season's yield, including North Fork and new discoveries.

The total of the above table is $667,500. To this should be added $40,000, which is known to be the approximate output of sundry smaller diggings, not given in the above list in 1901; about $6,000 output in 1899 derived mostly from Slate and Myrtle creeks and various points on South Fork, and $3,000 to $4,000 won from the Tramway and other bars in previous years, all of which to date gives an aggregate yield for the Koyukuk district of about $717,000.

The relatively low yield, not much exceeding $100,000 for the year 1902, is reported to be due to the exceptional dryness of the season and consequent lack of water for operations on most of the creeks. On Gold Creek but little sluicing could be done, but while the water lasted the yield was rich. On one claim the owners are reported to have washed out $12,000 in ten days.

In connection with the above statement concerning gold should be mentioned the reported recent discovery of supposedly promising pyritiferous gold-bearing ore near the head of Alatna River, principally on the divide between it and Noatak River, which flows westward into Kotzebue Sound. The locality is northwest of Bergman, in approximate latitude 67° 40′, longitude 155°. The men who made the discovery state that the locality is 170 miles from Bergman, but this must be by the river route where the distance traveled is necessarily greatly increased by the very tortuous course of the Alatna. Our knowledge concerning the geography of this region is not definite, but the distance across country in a straight line from Bergman to the Koyukuk can hardly exceed 100 miles, and it is probably less.

The discovery seems to have been made by a party of prospectors and miners who visited the region by sled during the winter of 1902–3, and in company with others continued to prospect there during the summer of 1903. At present a score or more men are reported to be interested in the holdings.

The country rock is described as quartzite, slate, and schist, and is inferred by the writer to be in all probability a westward extension of the Fickett series (Carboniferous) which is prominently developed on John River, 60 miles distant, and in which, as indicated on the map (Pl. III) and on page 106, a mineralized zone in the slate and quartzite was observed by the writer in 1901. Without here affirming that the mineral deposits of these two regions are connected, it should be noted that the newly discovered Alatna deposits seem to lie directly in the trend of the John River deposits and have the same strike. This suggests that the deposits of the two regions may represent the same mineral belt.

The Alatna ore deposits are reported to consist of six or more veins, or ledges, known as the Copper King, Copper Queen, Lucky Six, Mammoth, Iowa, Gray Eagle, Silver King, and Ground Hog. They are on an average about 1 mile apart, and are accordingly included in a belt about 6 or 7 miles in width. They lie nearly parallel and trend in a northeast-southwesterly direction, and, so far as prospected, are in general nearly vertical, or dip about 75° NW.

About half of the veins are reported to have a width of approximately 75 feet, while the minimum width of the smallest is given as 10 feet. Some of the veins have been traced by croppings for distances varying from several thousand feet to 2 miles.

Through the courtesy of Mr. Prindle the writer has received for study six of these Alatna ore specimens, brought out by the miners in the fall of 1903. In these specimens the ore consists essentially of iron pyrites and quartz, with also chalcopyrite (copper pyrites) which is conspicuous in two specimens. With the chalcopyrite is associated a little bornite and a trace of malachite. Another specimen is composed essentially of stibnite or sulphide of antimony and epidote. One specimen contains feldspar as a gangue mineral in addition to quartz, and is locally stained reddish brown by hematite or iron oxide, which is seemingly an alteration product of the pyrites.

The quartz is largely of the finely granular sugary type, and often remains as a porous honeycombed or coralline-like mass where the metallic contents of the ore have been leached out of the more exposed croppings. This "skeletonized" mass is occasionally traversed by small discontinuous stringers of firmer, greasy-lustered, and evidently younger quartz, producing a semibanded appearance, which, considered in connection with slickensiding and planes of weakness exhibited by other specimens, shows that ore deposition was followed by rock movement and consequent crushing, which produced fractures, into which the barren stringers were subsequently deposited by silica-charged solutions.

The specimens at hand contain both white and yellow iron pyrites, which is mostly fine-grained and normally occurs massive with the quartz, but in a few cases an imperfect parallelism, or banding, apparently representing depositional layers of quartz and pyrites in varying amounts, is perceptible.

The value of the ore rests in its auriferous content. At least three of the larger veins are reported, from assays made for the owners in San Francisco, to carry from $40 to $90 per ton in gold.[a] The gold seems to be contained, very finely disseminated, in the pyrites, for so far as known no free gold is visible. None was seen in the specimens examined by the writer.

Should these deposits prove to be of economic value, it is noteworthy that besides being easily accessible by land, they can be approached at high water by way of the Alatna River with flat-bottom steamboat to a point within 6 miles of the locality, and at low water to a point within 20 miles. The region is reported to contain a large amount of small timber having a stumpage of about 1 foot in diameter.

COPPER.

The only indications of copper seen in this northern country by the writer were in detached fragments of quartz, apparently derived from veins, and carrying some iron pyrites, copper pyrites, malachite, and a trace of bornite. Such specimens were found sparingly in the river gravels on the upper Chandlar in 1899.[b] Some, seen in the possession of prospectors, were reported to have been collected on Mineral Creek, at the head of Chandlar Lake, on the west side. A ledge is also reported to have been found on East Fork of the Chandlar, which assayed well in copper. But the ore is not known to occur in quantities of commercial value.

In the Koyukuk Basin the indications are much the same as above described, the occurrences being on the upper waters or the tributaries heading in the limestone mountains. The principal specimens seen by the writer during the recent work consisted of waterworn fragments found in the John River gravels and derived apparently from quartz veins. They contained some copper pyrites and a little bornite. Similar specimens were seen in the hands of Kowak natives on John River. What is supposed to be a vein of considerable size, containing iron and apparently copper pyrites, was observed in a steep limestone cliff of the Skajit formation overlooking the river, where no examination or collection could be made.

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[a] The Survey has just completed the assay of four of the above-described ore specimens, with the following results, in ounces per ton: Specimen B, gold 0.05; silver none. Specimens C and D, gold, trace; silver, trace. Specimen F, gold 0.10; silver, 0.08. These results are not promising.

[b] Op. cit., p. 482.

LEAD.

Galena is known to occur in the Bettles limestone on the upper waters of the Chandlar and the Koyukuk. It is also reported on East Fork of the Chandlar. Specimens have been seen from Bettles River. Some reported to be from the upper part of Hokotena River or Wild Creek, which is the next large river above John River, were presented to the writer by Messrs. Windrick and Bettles. In one instance the Wild Creek galena is associated with, or partly incloses, quartz crystals five-eighths inch in diameter and an inch or more in length, while in another instance the associated quartz seems to be chalcedonic. The ledge occurs on Michigan Creek (the large east-side tributary of the Hokotena), 3 miles above its mouth, and is supposed to be in the Skajit formation. It is reported to be of considerable size. Those who have prospected it are hopeful that it may prove to be of economic value. It is reported to assay some silver and several dollars in gold per ton.

On the east side of the divide between Middle Fork and South Fork, opposite the head of Minnie Creek, a limestone mountain of considerable size is reported by prospectors, in which galena is said to occur in large quantity.

ANTIMONY.

Pebbles and angular fragments of antimony sulphide, sometimes several inches in diameter, are found in the gravels of Gold Creek. A specimen of this mineral was determined in the chemical laboratory of the Survey to be a good grade of relatively pure stibnite. It is traversed by quartz stringers. Judging from the resemblance of the quartz to that seen in the Lake quartz-schists and the locality at which the antimony occurs it is inferred that this rock is probably the source of the ore.

Owing to the remoteness of the region the copper, lead, and antimony ores are not in themselves likely to prove of economic value unless the deposits are very exceptional in quantity and character.

ZONES OF METALLIFEROUS MINERALIZATION.

In the Totsen series.—About 40 miles above the mouth of John River, near the northern edge of the Totsen series, as shown on the geologic map (Pl. III), the mica-schists, in an area several miles wide trending northeast and southwest, across the valley, are stained a pronounced reddish-brown or hematite color, denoting apparently a zone in which iron pyrites and other sulphides occur more or less abundantly in the schist. Though the rock could not be examined in detail, it seems probable that the stain is due to iron oxide derived from the sulphides by oxidation. The residuary soil formed by the disintegration of the schist in this belt is not nearly so red as the rock itself, but is rather of a yellow-ocher or limonite color, which seems to be due to more extensive oxidation and weathering or to leaching out of the mineral matter.

In the Fickett series.—Toward the northern edge of the Fickett series, east of John River, in the Fork Peak region, where the country rock consists of heavy-bedded gray and pinkish quartzite and slate, there is a belt about 2 miles wide which is stained bright reddish brown, purple, and some other colors. As shown on the map, this belt also trends northeastward a distance of apparently about 15 miles to a point where the Fickett series gives way to the Lisburne formation. It seems also to extend southwestward beyond John River, but in that direction it is apparently not so conspicuous.

Here again the stain, which is surficial, is due to iron pyrites acted on by the process of weathering. A fresh fracture surface in hand specimen shows the zone of stain or weathering to be nearly always definitely marked, but in its penetration of the rock it may vary in different cases from a mere film to a zone nearly one-fourth inch in thickness. As the rock is known to contain iron pyrites very finely disseminated, and all of the five stained specimens tested by the chemical laboratory were found to contain ferric oxide (Fe_2O_3), with some sulphuric oxide (SO_3) present in four cases, the stain seems undoubtedly to be iron oxide derived from the pyrites by process of weathering. The brilliant peacock or bornite color, which by the inexperienced prospector would readily be mistaken for indications of copper, is iridescent hematite. The specimen in which no sulphuric oxide occurs was found to contain also siderite ($FeCO_3$).

Whether these zones of mineralization may prove to be of economic value can not be affirmed at present, as the rapid progress of the party through the country did not permit opportunity for examination. It may be noted, however, that both zones are closely related to formational boundaries, the southern being near the unconformable and probably deformational contact of the Totsen series with the Skajit formation, while the northern lies along the fault contact of the Fickett series with the Stuver series and Lisburne formation; and both zones trend in a general way parallel with the dominant jointing or major structure of the mountain range. The localities at which placer gold claims have been staked by prospectors, and gold colors panned by the writer on John River, lie within the southern zone.

COAL.

GENERAL STATEMENT.

Coal in one form or another, and varying in age from Tertiary to possibly Carboniferous, is more or less widely distributed in northern Alaska. It occurs in the Koyukuk drainage on the south side of the mountains, in the plateau on the Anaktuvuk, in the coastal plain on the Colville, and on the northwestern coast, in what is commonly known as the Cape Lisburne region, at Wainwright Inlet, Cape Beaufort, and several points between Cape Beaufort and Cape Lisburne (Pl. V).

KOYUKUK REGION.

Koyukuk River.—On Koyukuk River, in what was formerly supposed to be the Kenai[a] series, lignite and coaly material in small amount is common in the sandstone, grit, and especially in the conglomerate. The best occurrence is just above Tramway Bar, where there is a vein nearly 12 feet thick, of which the middle 9 or 10 feet seems to be relatively pure fuel. Its analysis is given under No. 187 in the table on page 114, which shows it to be a low grade of bituminous coal. There seems to be no reason why with development this vein should not prove serviceable for local use.

John River.—Coal detritus in considerable quantity and of a character to suggest the probable occurrence of coal of economic value somewhere in the region north of this locality was seen in the John River gravels near the base of the Endicott Mountains. This coal may apparently with safety be called a good grade of bituminous. It breaks with a conchoidal fracture and has a bright shiny or glossy black surface.

ARCTIC SLOPE.

Coal has been found also at several points on the Arctic slope, notably on Anaktuvuk and Colville rivers.

Anaktuvuk River.—Coal was first encountered by our party on the Anaktuvuk, in the east bank, about 5 miles above the mouth of Tuluga River, about 130 miles from the Arctic coast, in latitude 69° 11′, longitude 151° 4′. This coal is of Upper Cretaceous age, forming part of the Nanushuk series, from which the fossils at this locality were collected. As shown in Pl. XII, *B*, the rocks here dip steeply south, at an angle varying from about 80° to nearly vertical, and rise to a height of 100 or more feet above the river flats. The coal is conformable with the rocks of the series of which it forms members and occurs in several beds, each a foot or more thick. It is laminated parallel with the bedding, apparently denoting pressure. Though in the weathered state it has the appearance of lignite, it is shown by No. 607 in the table of analyses on page 114 to be a bituminous coal, having a fuel ratio of about 1.20. The quantity thus far observed, however, is hardly sufficient to lead to the belief that the bed will prove of economic value in so remote a region.

Colville River.—At about 30 miles north of the above locality and at a distance of 100 miles from the coast, on the Colville, in the region of the mouth of the Anaktuvuk, in latitude approximately 69° 32′, longitude 151° 30′, lignitic coal appears in considerable quantity. It is found in the Colville series, which underlies the Arctic Coastal Plain in this region, and here rises 200 feet above the river nearly to the surface of the plain, forming bluffs along the left or west side of the river for 10 miles both above and below the mouth of the Anaktuvuk. (See Pl. VIII.)

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[a] Schrader, F. C., Reconnaissance along Chandlar and Koyukuk rivers, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 477 and 485.

Here the coal is abundant and conspicuous. In the talus at the foot of the bluffs it is strewn about in detached blocks and bowlders ranging from 1 to several feet in diameter. Its occurrence in place in the bluffs is for the most part in the lower half of the section, where it appears in half a dozen or more beds that are from 1 to 3 or more feet in thickness, and are conformable with the Colville series, of which they form members. The beds lie for the most part nearly horizontal or dip very gently northward, and are well exposed for a distance of probably 10 or more miles along the river. They are represented by the dark or black layers in Pl. VIII.

The associated rocks, of which a fuller description is given under the head of geology, consist in general of heavy beds of partially consolidated silt, soft shale, soft sandstone, very impure limestone, and intermediate types of deposits.

So far as observed in ascending the geologic section, the coal layers in most cases are underlain by a heavy bed of soft sandstone or shale 3 to 6 feet thick, with an intervening thin 6 to 8 inch layer of shaly under clay. The shale bed often contains fragmental lignitic plant remains.

As shown in the table of analysis (p. 114), where it is indicated by No. 620, the coal seems to be a good quality of lignite, with volatile matter 30.33 and fixed carbon 30.27. As the specimen was considerably weathered, it is probable that the analysis here given may fall somewhat short of representing the average efficiency of the coal. On several occasions the coal was used by the party in camp fires, and gave good satisfaction. It burned readily and yielded considerable heat.

The coal in general presents a dull-black appearance, and at first appears massive, but on closer observation is found to contain nearly horizontal, more or less discontinuous beds and thin layers of highly metamorphosed material, which is of a deeper black and has a somewhat high anthracitic luster. The main body of the coal seems to be composed largely of a mass of similarly well-metamorphosed, short, and glistening needles or spicules, variously compressed together in horizontal arrangement, presenting somewhat the appearance of an imperfect fibrous or woody structure.

From the known occurrence of such lignite and lignitic plant remains in the Kenai (Oligocene) elsewhere in Alaska, and from the position of this coal in the beds above the Upper Cretaceous and below fossil-bearing Pliocene beds, the coal is inferred to be Oligocene. The vegetable fragments collected from the shale beneath the coal were examined by Doctor Dall, who suggests that they are probably the needles of *Sequoia langsdorffii* or some related conifer. He also suggests that the mass of this coal is probably composed of the trunks of *Sequoia*.

From an economic point of view, it should be stated that this coal is probably not suitable for export or for steaming purposes, and, though it is abundant it is unlikely, from its remoteness, under present conditions of the country, to prove to be of value for local use. It is not difficult of access, however, and could readily be as Wainwright Inlet, a distance of about 200 miles. It is not certain, however, that the beds at these various points represent the same coal field or even that they all occur in the same formation. Though these coals have been somewhat exploited, and numerous fossils, ranging from early Paleozoic to Mesozoic, have been reported from the region, no definite conclusion has been reached concerning the geologic age of the rocks in which the coals occur.

Wainwright Inlet.—The most northerly occurrence of the coal yet reported along this coast is at Wainwright Inlet, latitude 70° 37′, longitude 159° 45′. Here it is said by Mr. Woolfe,[a] who discovered it in 1889, to occur on the banks of Koog River, which flows into the inlet. As the river is shallow at its mouth, flat-bottomed boats or lighters would be required for getting the coal to the sea. The coal is described by Mr. Woolfe "as being of better quality and containing less detritus than the Cape Lisburne mineral. It appears to be a light but hard lignite, burning briskly, with but little ash." It is somewhat surprising that this coal should excel the Cape Lisburne coal in fuel efficiency, as the latter is believed to be the older, more highly metamorphosed, and carbonized. Though the writer was not able to visit the Wainwright Inlet exposure, at a point about 20 miles southwest of the inlet paleontologic evidence showed the country rock to be probably Jura-Cretaceous (p. 74). Judging from topographic criteria, the same formation seems to extend beyond Wainwright Inlet. Samples of apparently good coal were found near the place where the fossils were collected. Analysis of one of these, however, No. 653 in the table (p. 114), shows that it is a lignite.

Though coal float is found in the beach gravels at several localities along the coast, actual outcrops of coal were not seen and are probably not numerous.

Cape Beaufort.—Cape Beaufort, in latitude about 69° 10′ and longitude 163° 36′ (see Pl. V), marks the coastal terminus of the line of demarcation between the very gently rolling or nearly flat lowland tundra country on the north and the more hilly and low mountainous region on the south which merges with mountains that terminate in Cape Lisburne. It lies about 70 miles northeast of Cape Lisburne. The term cape is hardly applicable to Beaufort, however, as there is here no real promontory, but only a ridge rising to a height of about 800 feet above the uniform shore line.

A 6-foot vein of coal occurs in the folded and faulted sandstone of this ridge. It is probably best exposed about one-eighth to one-fourth of a mile from the coast, whence it seems to extend farther inland and with care can probably also be traced to the coast. So far as observed, the vein dips gently southward with the rocks of the region. As shown in the table of analyses under No. 665, page 114, this is a good bituminous coal.

It may be well to note that Doctor Dall, in his report on Alaskan coal and

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[a] Report on population and resources of Alaska at the Eleventh Census, 1890, Washington, 1893, p. 133.

The Corwin mines, which at present seem to be by far the most important, accessible, and productive, are situated farther to the southwest, near the southwestern limit of the coal measures referred to by Dall, and about 30 miles east of Cape Lisburne (see Pl. V). Coal is reported to have been obtained here by the whaling vessels as early as 1879. Its occurrence, so far as observed, is in 10 or 12 beds, varying from 1 to 16 feet in thickness, all being apparently quite persistent. The edges of these beds are exposed for a distance of about three-eighths of a mile along the coast, which cuts them diagonally, forming a steep cliff that rises from 30 feet on the west to more than 100 feet above tide on the east, where it attains its maximum in a low prominence known as Corwin Bluff. The coal beds, conformable with the country rock in which they occur, strike N. 45° W. and dip southwestward at an angle of 36°, as shown in Pl. XIII, *B;* but eastward, in Corwin Bluff, where the rocks are more disturbed, the dip steepens.

The country rock in which the coal occurs, as shown in the above view, is sandstone, shale, and slate, and is probably Jura-Cretaceous. It is more fully described under the head of geology, page 72. As noted, it very much resembles the rocks of the Anaktuvuk series, but is supposed to be older.

Some of the coal in the Corwin mines has been partially crushed, but not greatly damaged, by rock movement. In mining much of it is taken out in large blocks, 1 to 2 or more feet in diameter, and nearly all of the beds are comparatively pure. Average samples collected by the writer gave the analyses under numbers 669 and 671 in the accompanying table, page 114, showing the product to be a bituminous coal of fair grade, with a fuel ratio of 1.10 and 1.30. It is, however, hardly satisfactory for blacksmithing or steaming purposes. It was used on the steamship *Arctic*, on which the party took passage for Nome, but with much the same results as indicated by Mr. Woolfe. Though it burns readily and produces steam quickly, it is of low specific gravity and not lasting. It takes about double the amount of this coal as compared with Comax coal to maintain a given steam pressure. It burns with little smoke, but produces a large amount of ash and clinker. This instance, however, can hardly be considered a fair trial, as, owing to the want of timber, the facilities for mining were so poor that much "bone," rock, and dirt, or foreign débris found its way into the coal and thence into the furnace. The coal is reported to be good for cooking and household purposes.

Mr. Charles L. Norton,[a] of the Massachusetts Institute of Technology, is said to have made the following report to the Corwin Trading Company on "Cape Lisburne coal," which was probably collected at or in the region of the Corwin mines:

"I find that the specimens of Alaska coal which you recently sent me have a calorific power of 7,560 calories per gram. This is quite as good as the average western coal, and is not more than 10 per cent inferior to the best eastern coals."

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[a] Brooks, A. H., The coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 566.

should be noted that in the shale associated with the coal there is reported to have been found by Mr. Dumars a small specimen of *Lepidodendron*, which has been determined by Mr. David White, who states that it is related to *Lepidodendron chemungense*, and that it indicates an age for the shale either of Upper Devonian or Lower Carboniferous.

Mr. Maddren also reports that in the valley between Cape Dyer and The Ears (shown in fig. 1) a syncline of shales occurs containing at least one exposure of coal along the low sea bluff that rises from 50 to 100 feet above tide. He also states that just south of Cape Lewis there is a bluff of shales that seem to contain "coal blossom."

ANALYSES OF COAL.

The following analyses were made by Mr. George Steiger, chemist of the Survey:

Table of coal analyses.

	187 Koyukuk River above Tramway Bar.	607 Anaktuvuk River.	620 Colville River.	653 Wainwright Inlet.	665 Cape Beaufort.	669 Corwin mines.	671 Corwin mines.	Cape Lisburne.[a]
Moisture	4.47	6.85	11.50	10.65	7.18	10.47	7.23	3.75
Volatile matter	34.32	36.39	30.33	42.99	36.38	40.12	38.68	43.75
Fixed carbon	48.26	43.38	30.27	42.94	51.23	46.16	50.05	47.39
Ash	12.95	13.38	27.90	3.42	5.21	3.25	4.04	5.11
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulphur	....	.54	.50	.62	.48	.27	.23	.36
Phosphorus pentoxide	....	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	....
Coke	....	None.	None.	None.	None.	None.	None.	....
Fuel ratio	1.40	1.20	....	....	1.4	1.10	1.30	1.08

CLIMATIC CONDITIONS.

METEOROLOGIC RECORD FOR 1899.

The following is a record of meteorologic observations made by the writer on a reconnaissance along Chandlar and Koyukuk rivers in 1899, mainly in latitude 65° to 68°, longitude 145° to 158°. The localities at or near which they were made are designated by the position of the dates (month and day) on the map.[b]

The thermometer used in this work is an H. Green, cylindrical bulb, Fahrenheit scale.

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[a] Brooks, A. H., The coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, p. 565.

[b] Schrader, F. C., A reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, opposite p. 448.

The localities refer to camps pitched by the party en route at the close of its day's traverse. Hence the morning observation of any given date was usually made at the camp preceding the one of the date by which the observation is designated on the map, and the 2 p. m. observation of the same date was made at a point about midway between the two camps.

Meteorologic observations along Chandlar and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Temperature.	Clouds: Kind and amount.	Wind: Direction and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
Chandlar River:	*Degr. F.*					
June 24, 7 a. m.	52	Ci. 8	SW. 15.	28.98	Threatening	
2 p. m.	60	Ci. 2	SW. 15.	29.05	Bright and fine	
9 p. m.	50	Ci. 4	SW. 20.	29.06	do	
25, 7 a. m.	51	Ci. 1	SW. 20.	29.15	do	
2 p. m.	55.6	Ci. 6	SW. 15.	29.15	do	
9 p. m.	54	Ci. 2	SW. 10.	29.16	do	
26, 7 a. m.	51	Ci. 1	SW. 5.	29.12	do	
2 p. m.	57.5	N. 9	SW. 4.	29.6	Showery and rain.	
9 p. m.	54.6	N. 8	SW. 15.	29.6		Temperature water, Chandlar River = 54.5°.
27, 7 a. m.	48	Ci. 1	SW. 20.	29.12	Bright	
2 p. m.	55	Ci-cu. 8	SW. 10.	29.1	Bright (?)	(?).
9 p. m.	48	Ci-cu. 4	0	29.11	Bright	
28, 7 a. m.	58	Ci-cu. 2	SW. 2.	29.05	do	Two good showers last night.
2 p. m.	59.5	Threaten'g 8	SW. 3.	29.0	Showery	
9 p. m.	53	N. 10	NNW. 5.	28.9	do	Stormy on mountains.
29, 7 a. m.	54	N. 9	W. 5.	28.9	do	Do.
2 p. m.	59	Cu-S. 8	W. 2.	28.92		Mountains smoky; temperature river = 52°.
9 p. m.	52.5	N. 10	SW. 20.	28.8	Showery	Blustery.
30, 7 a. m.	44.5	Cu-n. 9	SW. 20.	28.8		Do.
2 p. m.	46.5	N. 10	SW. 15.	28.85	Steady rain	Showery all a. m.
9 p. m.	46.5	N. 10	SW. 10.	28.85	do	Rained all p. m.
July 1, 7 a. m.	44	N. 10	SW. 5.	29.8	do	Rainy all night.
2 p. m.	47	N-cu. 8	SW. 8.	29.06	Showery	Clearing (?).
9 p. m.	49	N-cu. 6	0	29.05	do	Do.
2, 7 a. m.	53	Ci-cu. 5	W. 20.	29.1	Bright	Temperature river = 49°.
2 p. m.	54	N. 8	SW. 30.	28.9	Showery	Showers.
9 p. m.	52	N. 7	SW. 20.	28.9	do	Do.
3, 7 a. m.	54	N. 3	SW. 20.	29.04		Blustery.
2 p. m.	57	Ci-cu. 2	SWW. 20.	29.1	Clear	Clear and fine; sunset at 10 p. m.
9 p. m.	49	Ci-cu. 1	S. 77° W. 1.	29.2	do	Clear and fine.
4, 7 a. m.	50	Ci. 2	S. 77° W. 5.	29.30	Bright; hazy	Hazy; bright.
2 p. m.	62.5	Ci. 3	S. 77° W. 20.	29.20		Threatening.
9 p. m.	55	N. 8	SW. 20.	29.0	Threatening	
5, 7 a. m.	56.5	Ci. 2	SW. 20.	28.90	Bright	Bright.
2 p. m.	58	Ci. 2	W. 30.	28.1	do	Bright. On lava butte at edge of mountains and Yukon flats.
9 p. m.	64	Ci. 3	W. 20.	28.9	do	Bright.
6, 7 a. m.	60.5	Ci-cu. 4	W. 20.	28.9	do	Bright; temperature river below Forks=55°, 11 a. m.; temperature Lake Fork = 55.5, 11.30 a. m.
2 p. m.	66.5	N. cu. 8	W. 20.	28.7		Cloudy; temperature above Forks=55.8, 12 m.
9 p. m.	56		W. 1.	28.18	Heavy shower at 5 p. m.	Bright.
7, 7 a. m.	52	3	W. 10.	28.9		Hazy.
2 p. m.	65	0	W. 5.	28.8		Fine warm day.
9 p. m.	55	0	0	28.8		Do.
8, 7 a. m.	53	0	W. 2.	28.75		Fine warm morning.
2 p. m.	69	0	W. 10.			Warm day; temperature river =56°.

Meteorologic observations along Chandlar and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Temperature.	Clouds: Kind and amount.	Wind: Direction and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
Chandlar River—Continued.	*Degr. F.*					
July 25, 7 a. m.	56	Ci-cu. 2	SWW. 5.		Bright	
2 p. m.	68	Ci. 1	SWW.			Fine, comfortable day.
9 p. m.	59.5	Ci-cu. 2	0			Do.
26, 7 a. m.	59.5	0	SWW.			Fine; somewhat hazy.
2 p. m.	71	0	SWW. 5.			Fine.
9 p. m.	55	0	0			Fine; moonlight.
27, 7 a. m.	61	Ci. 3	NW. 10.			Fine; warm.
2 p. m.	73	Cu-n. 5	NW. 15.		Showery about lake.	Do.
9 p. m.	60	Cu-n. 6	0		Showery in p. m.	Fine; comfortable.
28, 7 a. m.	60	Cu-n. 5	NW. 5.			Warming.
2 p. m.	61	Ci-cu. 3	NW. 15.			Fine day.
9 p. m.	46	0	NW. 5.			Do.
29, 7 a. m.	49	0	0			Warming.
2 p. m.	58	0	0			Location: Summit of Chandlar-Koyukuk portage at 3,500′.
9 p. m.	48	0	0			
30, 7 a. m.	37	0	0			
2 p. m.	68	0	NW. 5.			
9 p. m.	50	Hazy	0			
31, 7 a. m.	41	Hazy	0			
2 p. m.	61	Hazy	0		Showery	
9 p. m.	52	N. 1	0		Raining	
Aug. 1, 7 a. m.	51	Ci-cu. 5	0		Rain in night	Clearing.
2 p. m.	74	Ci. 2	NW. 5.		Hazy; bright	Fine.
9 p. m.	62	N. 6	0			
Koyukuk River:						
Aug. 2, 7 a. m.	67	Ci-cu. 4	NW. 5.		Hazy; bright	Fair.
2 p. m.	74	Ci-cu. 6	NW. 8.			Cooling.
9 p. m.	60	N. 7	NW. 5.		Showery	Comfortable.
3, 7 a. m.	57	N. 10	NW. 4.		Rained hard 49 minutes.	Rainy and foggy.
2 p. m.	52	N. 10	0		Rainy	
9 p. m.	45	Ci-cu. 4	W. 4.		Clearing	Clearing and cool.
4, 7 a. m.	52	0	W. 4.			Warming fast (?).
2 p. m.	46	S. 3	SW. 7.			Cold. Location: Mount Horace at 5,600′.
9 p. m.	45	Cu-n. 5	0			Do.
5, 7 a. m.	54	Cu. 4	0			Heavy frost.
2 p. m.	56	Cu-n. 9	SW. 4.			Cool.
9 p. m.	54	Cu-n. 9	0			Comfortable.
6, 7 a. m.	48.5	N. 10	0		Rainy	Cool.
9 p. m.	54	N. 9	0		do	Comfortable.
7, 7 a. m.	53.5	N. 9 and fog.	W. 5.		Raining all night.	Clearing (?) and colder; river rose 2 inches.
2 p. m.	65	N. 9 and fog.	0			Clear(?) warming (?).
9 p. m.	50	Ci-cu. 2	0			Evening clearing (rained during night).
8, 7 a. m.	50	0	0			Bright and warming.
2 p. m.	67.5	Ci-cu. 8				
9 p. m.	51	Ci-cu. 4	0			Showery 5 to 8 p. m.
9, 7 a. m.	63	0	NW. 4.			Bright.
2 p. m.	67.5	Ci-cu. 4	NW. 5.			Temperature creek=55°.
9 p. m.	45	Ci. 3	0			Cool.

Meteorologic observations along Chandlar and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Temperature.	Clouds: Kind and amount.	Wind: Direction and velocity in miles per hour.	Barometer. (Aneroid.)	Weather.	Remarks.
Koyukuk River—Continued.	*Degr. F.*					
Aug. 27, 7 a. m.	54	N. 10	SW. 3.		Rainy all night	Warm.
2 p. m.	56	N. 10	SW. 4.		Showery	Do.
9 p. m.	53	N. 10	SW. 5.		Raining	Rainy all day.
28, 7 a. m.	48	N. 10	SW. 2.		Rainy	Rainy morning and last night.
2 p. m.	48.5	N. 10	SW. 6.		do	Rainy.
9 p. m.	47.5	Ci-n. 8	SW. 7.			Clearing (river rising).
29, 7 a. m.	47	Ci-n. 8	SW. 6.			Clearing (?).
2 p. m.	52	Ci-n. 7	SW. 10.		Stormy	Clearing (?) (river rising).
9 p. m.	47	Cu. 5	SE. 4.			Showery all day; clearing.
30, 7 a. m.	42	Ci-n. 7	0		Some fog	Clearing (?).
2 p. m.	54	Cu-n. 8	SW. 8.		do	Showers in a. m.
9 p. m.	46.5	Cu-n. 7	0		do	Stormy in p. m.
31, 7 a. m.	43	Cu-n. 5	0		do	Fine morning; clearing (?).
2 p. m.	51	Ci-s. 4	SW. 10.			Fair.
9 p. m.	39	Ci-s. 3	SW. 2.			Fine mackerel sky in north.
Sept. 1, 7 a. m.	36	Hazy	NE. 3.		Some fog	Fine morning; frost.
2 p. m.	60	Hazy 3	SW. 2.			Fine mackerel sky in S. and SE.
9 p. m.	50.5	Cu-n. 8	0			Threatening.
2, 7 a. m.	45.5	Cu-n. 7	0			
2 p. m.	52.5	Ci-cu. 2	SSW. 3.			Fair day, somewhat hazy.
9 p. m.	45	Ci-cu. 3	SWW. 2.			Fair evening.
3, 7 a. m.	45	Ci. 3	0			Fair morning.
2 p. m.	61	Ci-s. 4	E. 7.			Fair day.
9 p. m.	52	Cu-s. 7	0			Dubious.
4, 7 a. m.	51	N. 9	0		Showery during night.	Do.
2 p. m.	57	Cu-n. 8	0			Dubious (river 40°).
9 p. m.	51.5	N. 10	0		Rainy p. m	River fell 1 foot in 24 hours.
5, 7 a. m.	51	N. 10	0		Rainy all night	
2 p. m.	58	N. 10	SE. 4.		Rainy all a. m	River still falling.
9 p. m.	49.5	N. 10	0		Rainy p. m	River still falling; fell several inches since.
6, 7 a. m.	45	N-s. 9	0		Rainy all night	Do.
2 p. m.	55	Cu-n. 8	SW. 3.			
9 p. m.	47	Cu-s. 5	SW. 1.			Fair day and cooler.
7, 7 a. m.	47.5	Cu-s. 7	0			Cool.
2 p. m.	61	Ci-cu. 3	SW. 10.			Fine day (river 50°).
9 p. m.	47.5	Cu. 2	0			Fine day.
8, 7 a. m.	44	Ci. 1	NE. 12 (?).			Fine morning.
2 p. m.	58.5	Cu-s. 7	NE. 12 (?).			Fine day a. m. (river 51.5°).
9 p. m.	49	Ci-s. 1	NW. 2.			Fine evening.
9, 7 a. m.	44	Ci-s. 2	N. 3.			Fine a. m. (river 48°).
2 p. m.	50.5	S-n. 8	E. 8.			Fine a. m.; threatening now.
9 p. m.	48.5	S-n. 8	0			Moderately fair evening.
10, 7 a. m.	44.5	S-n. 9	0			Dubious (river 49°).
2 p. m.	54.5	Ci-cu. 2	NE. 1.			Cloudy a. m.; p. m. hazy, but fine (river 49°).
9 p. m.	48	N. 8	0		Showery	Fine day.
11, 7 a. m.	47	N. 10	SW. 4.		do	Very foggy and misty.
2 p. m.	53	Cu-s. 4	S. 15.			Fair day (river 50°).
9 p. m.	49	S. 2	0			Fine, cool evening.
12, 7 a. m.	34	Ci-s. 4	0		Fog, low and dense	Fine morning (frost).

Meteorologic observations along Chandlar and Koyukuk rivers essentially at 7 a. m. and 2 and 9 p. m., from June 19 to September 23, 1899—Continued.

Locality and date.	Temperature.	Clouds: Kind and amount.	Wind: Direction and velocity in miles per hour.	Barometer. (Aneroid).	Weather.	Remarks.
Koyukuk River—Continued.	*Degr. F.*					
Sept. 12, 2 p. m.	52.5	S-Cu	E. 2.		Threatening	Threatening (river 48.5°).
9 p. m.	49.5	Cu-n. 10	0		Rainy	
13, 7 a. m.	44.5	Ci-s. 2	0			Clearing; fair morning.
2 p. m.	52	S-n. 9	SW. 12.		Showery	Showery and threatening.
Lower Yukon River:						
Sept. 13, 9 p. m.	47.5	Cu-n. 6	SW. 16.			Stormy. Location; Koyukuk Station.
14, 7 a. m.	41.5	Cu-s. 4	SW. 20.		Rained hard in night.	Stormy, but clearing.
2 p. m.	51	Cu-s. 5	SW. 20.		Stormy (?)	Storming.
9 p. m.	39	S-n. 6	SW. 10.			Stormy at Nulato.
15, 7 a. m.	37	S-n. 8	SW. 15.		Showery (?)	Storming.
Nulato:						
Sept. 15, 2 p. m.	48	S-n. 9	SW. 10.		Showery	Do.
9 p. m.	32	S-n. 4	NW. 3.			Cold.
16, 7 a. m.	21	S-cu. 1	NE. 2.			Ice ¼-inch thick; fine morning.
2 p. m.	33	S-cu. 2	NE. 9.			Hazy.
9 p. m.	31	10	NE. 8.		Snowing hard	Snowed since 3 p. m., and snowing hard now.
Steamer Weare:						
Sept. 17, 7 a. m.	29.5	10	NNW. 8.		do	Snowed hard all night; 3 inches.
2 p. m.		10			do	Snowed most of the day.
9 p. m.						
18, 7 a. m.						
2 p. m.						
Holy Cross:						
Sept. 18, 9 p. m.						
19, 7 a. m.	32.5	9	SW. 2.		Snowing; scatteringly.	Clearing (?).
2 p. m.	37	6	SW. 1.		do	Do.
Andreafski:						
Sept. 19, 9 p. m.	33.5	Ci-cu. 4	0			Fair, moonlight evening.
20, 7 a. m.	27.5	Ci-cu. 8	0		Fog	Boat stopped by fog.
Steamer Weare 50 miles below Andreafski:						
Sept. 20, 2 p. m.	37	Ci-cu. 6	S.		Some fog	Blustery.
9 p. m.	34	10	10.		Snowing hard	Wintry.
Aphoon mouth:						
Sept. 21, 7 a. m.	33.5	N. 8	0			Fog.
Norton Sound:						
Sept. 21, 2 p. m.	39	Ci-s. 4	SW. 5.		Snowing	Fair p. m.
St. Michael:						
Sept. 21, 9 p. m.	35	10	W. 2.		do	
22, 7 a. m.	34	Ci-s. 10			Snowy	Threatening.
2 p. m.	35	10	Nearly calm.		Snowing	Snowed all a. m.
9 p. m.		10	Nearly calm.		do	Cold.
23, 9 a. m.	Frozen hard.	Ci-cu. 7	Nearly calm.			Do.
2 p. m.		Ci-cu. 4	SW. 10.		Snowing	Do.
9 p. m.		Ci-cu. 6	0		do	Do.

METEOROLOGIC RECORD FOR 1901, BY W. J. PETERS.

Snow was found to average about 6 feet deep in the Koyukuk Valley in April, and as the preliminary expeditions ascended the north tributaries flowing from the Endicott Mountains in April the depth was found to decrease until the grasses were visible in the floor of the passes. By June this deep snow had practically disappeared from the lowlands. Natives report that north winds blow through the passes of the Endicott Mountains with great force in winter, during which season it is dangerous to travel. It is not only dangerous to face the wind, but there is risk of the sled being broken by its being blown against projections in the smooth ice. Fogs were found on the pass in April and dense haze in July. In both cases this seems to have been blown in from the coast.

The following table, showing the temperatures at Uglaamie, 9 miles from Point Barrow, is taken from the report of the Ray expedition, 1881–1883:

Temperature observations at Uglaamie.

[In degrees Fahrenheit.]

Month.	Mean.	Maximum.	Minimum.
1881.			
November	0	30	−28
December	−18	....	....
1882.			
January	−15	20	−45
February	−23	− 2	−52
March	− 4	23	−30
April	− 4	32	−23
May	22	37	− 2
June	34	53	24
July	43	65	27
August	38	59	27
September	31	51	19
October	9	41	−22
November	− 7	29	−35
December	−17	8	−42
1883.			
January	−17	12	−42
February	− 6	24	−34
March	−13	26	−51
April	− 3	16	−30
May	23	38	−14
June	32	51	18
July	36	53	27
August	37	60	22

September, 1885:	
Lowest temperature during month	5° F
Highest temperature during month	69
Mean temperature during month	39
October, 1885:	
Lowest temperature during month	— 4° F.
Highest temperature during month	46
Mean temperature during month	16
November, 1885:	
Lowest temperature during month	—44° F.
Highest temperature during month	15
Mean temperature during month	— 9.5
December, 1885:	
Lowest temperature during month	—65° F.
Highest temperature during month	29
Mean temperature during month	—12.4
January, 1886:	
Lowest temperature during month	—70° F.
Highest temperature during month	31
Mean temperature during month	—13.5
February,[a] 1886:	
Lowest temperature during month	—65° F.
Highest temperature during month	26
Mean temperature during month	—22.5
March, 1886:	
Lowest temperature during month	—38° F.
Highest temperature during month	36
Mean temperature during month	— 3.8
April, 1886:	
Lowest temperature during month	—22° F.
Highest temperature during month	49
Mean temperature during month	13
May, 1886:	
Lowest temperature during month	14° F.
Highest temperature during month	65
Mean temperature during month	35
June, 1886:	
Lowest temperature during month	32° F.
Highest temperature during month	74
Mean temperature during month	49

"*Note.*—During the month of December, 1885, in one hour the temperature rose 29° F., barometer remaining quite steady. This sudden rise in temperature was closely followed by a terrible gale of wind. The thermometer, not the barometer, indicates an approaching gale. It is dead calm when the thermometer stands low, and during the gales the temperature always goes above zero. The more sudden the rise of thermometer the harder the wind blows and the more quickly it hauls. One should watch the thermometer closely and get under shelter if a gale is coming; for neither man nor dog can stand these gales. You must be under shelter. Have seen it snowing—that is a fine snow falling—when there was not a cloud in the sky and very light wind. It is advanced by some that there was a higher wind that carried the snow from the mountain peak.

---

[a] Mean temperature February 1 to 20 —33° F.

Temperatures on Dawson trail at 8 a. m., February to May, 1901—Continued.

Date.		Deg. F.	State of atmosphere.	Locality.
Mar.	13	13	....	Near Eagle City.
	17	—23	....	Mouth of Washington Creek.
	18	—22	....	Do.
	19	10	Snowstorm	Charlie River.
	20	—10	....	Do.
	21	— 8	....	Circle.
	22	— 4	....	Near Circle.
	23	2	....	Near Fort Yukon.
	24	0	....	Do.
	25	0	....	Fort Yukon.
	26	0	....	Do.
	27	—20	....	Mouth of Chandlar River.
	28	6	....	On Chandlar River.
	29	3	....	Do.
	30	2	High wind.......	Do.
	31	2	....	Do.
Apr.	1	24	....	Do.
	2	8	....	Do.
	3	6	....	Do.
	4	3	....	Do.
	5	4	High wind.......	Do.
	6	14	....	Do.
	7	18	....	Do.
	8	8	....	Do.
	9	4	....	Do.
	10	6	....	Do.
	11	4	....	Divide between Chandlar and South Fork, Koyukuk River.
	12	4	....	On South Fork, Koyukuk River.
	13	8	....	Slate Creek.
	14	3	....	Koyukuk River near Bettles.
	24	4	....	John River.
	25	10	....	Do.
	26	8	....	Do.
	27	2	....	Do.
	28	18	....	Do.
	29	16	....	Do.
	30	14	....	Do.
May	1	12	....	Do.
	2	22	....	Do.
	3	16	....	Do.
	4	18	....	Bettles.

Temperatures on Dawson trail at 8 a. m., February to May, 1901—Continued.

Date.	Deg. F.	State of atmosphere.	Locality.
May 5	20		Bergman.
6	22		Do.
7	24		Do.
8	27		Do.
9	12		Do.

Temperature at morning, noon, and evening at localities between Bergman and Arctic coast.

Date.	a. m.	Noon.	p. m.	Atmosphere.	Locality.
	Deg. F.	*Deg. F.*	*Deg. F.*		
May 1	19	33	26		Bergman.
2	14	44			Do.
9	19	33	26		Do.
10	14	44	24		Do.
11	14	34	24		Do.
12	34	35	25		Do.
13	33	36	31		Do.
14	35	38	31		Do.
15	35		36		Do.
16	30		31		Do.
17	31	40	26		Do.
18	28		38		Do.
19	35	39	42		Do.
20	43	56			Do.
21	48	44	40		Do.
22	37	45	41	Rain, 0.02 inch; light wind north	Do.
23	37	45	38		Do.
24	40	45	43	Fair	Do.
25	49	51	46	do	Do.
26	44	46	42	do	Do.
27	46	52	40	do	Do.
28	43	49	43	Rain	Do.
29	50	48	38	Snow for 36 hours	Do.
30	32	43	33	Snow; precipitation to date, 0.67	Do.
31	41	42	41		Do.
June 1	36	39		Rain	Do.
2	42	45	42		Do.
3	51	52	51		Do.
4	53	57	54		Do.
5	58	50	45	Wind southwest, cloudy; rain, 0.03.	Do.
6	38	44	37	Snow	Do.

Temperature at morning, noon, and evening at localities between Bergman and Arctic coast—Continued.

Date.	a. m.	Noon.	p. m.	Atmosphere.	Locality.
	Deg. F.	*Deg. F.*	*Deg. F.*		
June 7	35	45		Snow	Bergman.
13[a]	55		40	Fair	Do.
14	42		62	do	John River.
15	51		55	do	Do.
16	60		63	Fair, light wind southwest	Do.
17	67	67	52	Rain 6. p. m. to 8 p. m., 0.01	Do.
18	57		60	Cloudy	Do.
19	62	68	64	Fair	Do.
20	63		64	do	Do.
21	61		60	Cloudy	Do.
22	56		58	Fair	Do.
23	56		55	do	Do.
24	56		49	Fair; rain, 0.09	Do.
25	48		48	Rain, 0.26	Do.
26	42	52	52	Rain, 0.20; wind south	Do.
27	48	68	62	Fair	Do.
28	58	71	62	Fair; temperature (water) 52°	Do.
29	51		54	Rain, 0.02	Do.
30	58	60		Fair	Do.
July 1	56		55	do	Do.
2				Rain, 0.04	Do.
3	57		57	Light snow	Do.
4	50		44	Rain, 0.08	Do.
5	50		57	Fair, wind northwest	Do.
6	60		65	Fair	Do.
7	60		54	do	Do.
8	64		64	do	Do.
9	57		52	Drizzling rain	Do.
10	50		49	do	Do.
11	47		49		Do.
12	53		55		Do.
14	44		42	Rain, 0.20; strong wind north	Do.
15	44		51	Fair, light wind north	Do.
16	5				Do.
18			61	Fair, cloudy, wind south	Do.
19			63		Do.
20	62			Fair	Do.
21	68	80	70	do	Koyukuk-Colville divide.
22	72	74	72	do	Do.
23	68		60	do	Do.

[a] Most of the dates that follow appear on the accompanying maps, Pls. II and III, and designate the localities at or near which the respective observations were made.

Temperature at morning, noon, and evening at localities between Bergman and Arctic coast—Continued.

Date.		a. m.	Noon.	p. m.	Atmosphere.	Locality.
		Deg. F.	*Deg. F.*	*Deg. F.*		
July	24	76	85	80	Light showers	Anaktuvuk River.
	25	68	....	83	Cloudy	Do.
	26	66	....	60	Fair	Do.
	27	62	....	52	Rain, 0.20	Do.
	28	54	....	50	Rain, 0.17	Do.
	29	34	36	36	Rain, 0.27	Do.
	30	41	....	50	Rain, 0.05	Do.
	31	44	....	....	Fair	Do.
Aug.	1	55	....	64	.....do	Do.
	2	62	74	69	Fair, hazy	Do.
	3	44	69	64	Fair, smoky	Do.
	4	52	67	62	.....do	Do.
	5	54	63	58	Fair	Do.
	6	60	65	60	....	Do.
	7	60	58	64	Cloudy	Do.
	8	44	52	48	Rain 0.04	Do.
	9	46	50	44	River temperature 52°	Colville River.
	10	43	48	47	Cloudy, drizzling rain; river temperature 50°.	Do.
	11	48	52	42	Cloudy	Do.
	12	43	52	60	.....do	Do.
	13	48	55	51	.....do	Colville River delta.
	14	40	45	52	Light showers	Do.
	15	38	42	40	Cloudy, sleet and rain; wind south.	Do.
	16	38	42	42	Fair	Do.
	17	38	40	43	....	Harrison Bay.
	18	38	38	38	Cloudy, snow	Do.
	19	52	44	42	Fair	Do.
	20	44	46	44	....	Do.
	21	39	50	52	Fair	Near Cape Halkett.
	22	38	42	40	....	Pitt Point.
	23	42	42	42	....	Smith Bay.
	24	42	39	39	Cloudy, wind east	Do.
	25	37	38	36	Cloudy, rainy, strong wind east	Do.
	26	36	36	33	Snow squalls, all day strong wind east	Do.
	27	32	33	32	Snow squalls, strong wind	Do.
	28	32	32	32	Strong wind east	Do.
	29	31	34	32	Cloudy, wind east	Do.
	30	32	32	32	....	Do.
	31	33	33	32	Cloudy, snow squalls	Do.
Sept.	1	32	32	32	Wind northeast	Do.

Temperature at morning, noon, and evening at localities between Bergman and Arctic coast—Continued.

Date.	a. m.	Noon.	p. m.	Atmosphere.	Locality.
	Deg. F.	*Deg. F.*	*Deg. F.*		
Sept. 2	31	33	35	Snow squalls	Sinclair River.
3	35	35	35	Clear	Off Dease Inlet.
4	36	36	36	do	Cape Smyth.
5	36	36	36	do	Near Refuge Inlet.
6	37	35	32	do	Do.
7	34	34	34	do	Do.
8	35	....	35	do	Peard Bay.
9	33	....	31	do	Off Belcher Point.
10	30	....	30	do	Off Wainwright Inlet.
11	32	....	33	do	Near Wainwright Inlet.
12	33	....	33	do	Do.
13	32	....	32	do	Off Icy Cape.
14	35	....	38	do	Off Point Lay.
15	38	....	38	do	Near Cape Beaufort.
16	36	....	36	....	Do.
17	31	....	30	....	Cape Beaufort.
18	36	....	....	....	Off Cape Sabine.

The minimum temperatures recorded for the Koyukuk district at Coldfoot are reported to be −80° and even lower, but the instruments on which these records are based are not known. It is hardly to be supposed, however, that it becomes much colder here than at Circle, Dawson, and other points on the Yukon. Though grass and other feed was scarce, a horse is reported to have wintered at large on North Fork of the Koyukuk, on Mascot Creek, in 1902-3, and appeared to be in fair condition in the spring.

ARCTIC PLANTS COLLECTED.

The following plants, collected on the trip mostly by G. H. Hartman, have been identified, with the exception of the grasses, by Frederick V. Coville and W. F. Wight, botanists of the U. S. Department of Agriculture. The grasses were identified by Mr. Elmer D. Merrill. The localities of collections are designated by camp dates, which latter will be found on the topographic and geologic maps (Pls. II and III).

EQUISETACEÆ. (Horsetail family.)

Equisetum arvense L.

At camp, August 12.

Poaceæ. (Grass family.)

Arctagrostis latifolia (R. Br.) Griseb.

Point Barrow, September 4.

Poa arctica R. Br.

At camp, August 12.

Bromus arcticus Shear.

At camp, August 6.

Elymus innovatus Beal.

Cape Smyth, September 5.

Melanthaceæ. (Bunch-flower family.)

Zygadenus elegans Pursh.

At camp, August 5.

Salicaceæ. (Willow family.)

Salix.

Cape Smyth, September 5.

Salix.

Point Barrow, September 4.

Salix.

At camp, August 12.

Salix.

At camp, August 5.

Salix.

At camp, John River, altitude 1,800 feet, June 20–21.

Salix alaxensis (Anders.) Coville.

John River, June 24; John River Valley flats, July 8; at camp, John River, July 10; at camp, August 5; at camp, August 6; at camp, August 12.

Salix arbusculoides Anders.

At camp, John River, June 28; John River, 1,000 feet above valley, July 8; at camp, John River, July 10; at camp, August 6.

Salix glauca L.

John River, 1,000 feet above valley, July 8; at camp, Arctic slope, July 21; at camp, August 6; at camp, August 12.

Salix niphoclada Rydb. (apparently).

At camp, John River, July 10; at camp, Anaktuvuk River, August 5.

Salix ovalifolia Trautv.

At camp, Colville delta, August 14.

Salix pulchra Cham.

John River, June 24; John River, 1,000 feet above valley, July 8.

Salix richardsoni Hook.

At camp, East Fork of John River, July 16–17.

Betulaceæ. (Birch family.)

Betula.

At camp, Arctic slope, July 21.

SCROPHULARIACEÆ. (Figwort family.)

Pedicularis.
At camp, July 21.
Pedicularis verticillata L.
At camp, Anaktuvuk River, August 5.

CICHORIACEÆ. (Chicory family.)

Taraxacum.
At camp, Colville delta, August 14.
Crepis nana Richards.
At camp, August 6.

ASTERACEÆ. (Aster family.)

Solidago multiradiata Ait.
At camp, Anaktuvuk River, August 5.
Aster.
At camp, Anaktuvuk River, August 5.
Aster sibiricus L.
At camp, August 12.
Erigeron.
At camp, John River, July 10.
Tanacetum.
At camp, August 12.
Artemisia.
At camp, John River, July 10.
Artemisia norvegica Fries.
At camp, August 6.
Artemisia tilesii Ledeb.
At camp, August 12.
Petasites.
At camp, August 12.
Arnica.
At camp, John River, July 12.
Arnica.
At camp, August 12.
Arnica.
At camp, Arctic slope, July 21.
Arnica lessingii (Torr. and Gr.) Greene.
At camp, Anaktuvuk River, August 5.
Senecio.
Point Barrow, September 4.
Senecio lugens Richards.
At camp, August 6.

INDEX.

Page.
Abbe, Cleveland, jr., aid by 115
Alaska, investigations in 11–14
  outline map of 11
Alaska Commercial Company, acknowledgments to 13
Alatna River, gold-bearing ore on 102–104
  name of, note on 20
  reconnaissance up 20
Allen, H. T., cited on Endicott Mountains 40
  exploration by 29
Allen River, name of, note on 20
  See Alatna River.
Amphibole-schist. *See* Totsen series.
Anaktuvuk Pass, glacial deposits near 86
  glacial lakes at 85
  section west of, figure showing 51
  view near 56
Anaktuvuk Plateau, extent and character of 45–46
  view showing 42
Anaktuvuk River, Anaktuvuk series on, plate showing 70
  coal from, analysis of 114
  coal on, occurrence of 107
  Colville series on 82
  distances along, table showing 37
  fossils from, list of 80
  glacial deposits on 86–88
  Lisburne formation near 63
  Nanushuk series on 79
    plate showing 80
  profile across 46
  Recent deposits along 94
  topographic features along 48
Anaktuvuk series, age and correlation of 76, 97
  character and occurrence of 74–75
  structure of 75–76
    plate showing 70
    profile showing 46
Analyses, coal 114
Andreafski, meteorologic observations at and near 121
Antimony, occurrence of 105
Arctic coast, barrier reef and Eskimo grave near, plate showing 96
  character of 48–50
  coal on 107–109
  distances along, table showing 38
  fossils from 96
  inhabitants along, number and condition of 35–36
  meteorologic observations between Bergman and 127–130
  Recent deposits along 95–96
  view of 50
Arctic Coastal Plain, edge of, view of 50
  extent and character of 46, 81

Page.
Arctic Ocean, depth of 49
Arctic slope province, coast line of 48–50
  drainage of 46–48
  extent and character of 45–46
Area discussed, climatic conditions in 114–130
  geography of 38–50
  geologic history of 52–55
  geologic map of 40
  geology of 50–97
  location and general features of 38–39
  mineral resources of 98–114
  plants collected in 130–134
  topographic map of 38
Arkose. *See* Anaktuvuk series; Koyukuk series.
Barometer. *See* Climatic conditions.
Barrier reef on Arctic coast, plate showing 96
Barrow, Point, coast between Cape Lisburne and, character of 49–50
  coast between Colville River and, character of 48–49
  Recent deposits between Colville River and 95
    between Cape Lisburne and 96
  settlement at 36
  topographic features at 49
  trip from Bettles to, account of 21–24
Beaufort, Cape, coal at, occurrence of 110–111
  coal from, analysis of 114
  rocks exposed at 73
  topographic features near 50
Beechey, F. W., exploration by 26
Bell, J., exploration by 27
Bennett, Ben, work of 11
Bergman, glacial deposits near 90
  meteorologic observations between Arctic coast and 127–130
Bergman series, age of 78–79
  character and occurrence of 77–78
  correlation of 97
  structure of 78
Bettles, G. C., acknowledgments to 13
Bettles, trip to Point Barrow from, account of 21–24
Bibliography 31–33
Brauer, Charles, acknowledgments to 14
  reference to 36
Bremner, John, river named for 17
Brooks, A. H., cited on fossils from Glacier Bay limestone 57
  cited on fossils from southeastern Alaska 67
  letter of transmittal by 9
  work of 12
Burlingame, E. E. & Co., work of 14
Busby, E. S., acknowledgments to 18
Cache Lake, view from 56
California Creek, gold on, production of 102

Page.

- Campbell, Robert, exploration by ... 27
- Camping, manner of ... 15
- Canadian Development Company, acknowledgments to 13
- Cantwell, J. C., exploration by ... 29
- Cape. *See* next word of name.
- Cape Lisburne region, Fickett series in ... 72
  - fossils from, list of ... 66
  - geologic section in ... 41
  - map of ... 44
- Carboniferous rocks, description of ... 67–72
- Carter, T. G., and Marsh, S. J., exploration by ... 30–31
- Chandlar Basin, copper in ... 104
- Chandlar River, meteorologic observations on ... 115–118
- Chandlar River gravels, fossils from, list of ... 66
- Chert. *See* Nanushuk series.
- Chloritic schists. *See* Fickett series.
- Clara Creek, gold on, production of ... 102
  - nugget from, size of ... 101
- Clay. *See* Kowak clay.
- Climatic conditions, tables showing ... 114–130
- Coal, analysis of ... 114
  - occurrence of ... 106–114
- Coast along Arctic Ocean, character of ... 48–50
- Coastal region, recent deposits in ... 95–96
- Collier, A. J., cited on fossils of Seward Peninsula ... 58
  - reference to ... 71
- Collinson, R., exploration by ... 27
- Colville delta, extent and character of ... 47–48
- Colville Flats, extent and character of ... 47
- Colville River, bluffs on, view of ... 48
  - coal from, analysis of ... 114
  - coal on, occurrence of ... 107–109
  - coast between Point Barrow and, character of ... 48–49
  - distances along, table showing ... 37
    - between Cape Smyth and ... 38
  - fossil locality on, view of ... 84
  - mounds near ... 94
  - Pleistocene flats on, plate showing ... 96
  - Recent deposits along ... 94–95
  - topographic features along ... 46–48, 81, 94
- Colville series, character and occurrence of ... 81
  - coal in ... 107–109
  - correlation of ... 97
  - fossil locality on, view of ... 84
  - fossils from, list of ... 83
  - river bluffs in, view of ... 48
  - structure of ... 82
    - plate showing ... 82
- Conglomerate. *See* Bergman, Fickett, Stuver series.
- Contact Creek, Lisburne formation near ... 63, 64
  - moraine in valley of ... 85
- Cook, James, exploration by ... 25
- Copper, occurrence of ... 104
- Correlation of Anaktuvuk series ... 76, 97
  - of Corwin series ... 74, 97
  - of Fickett series ... 71–72, 97
  - of formations, table showing ... 97
  - of Lisburne formation ... 65–67, 97
  - of Nanushuk series ... 80–81, 97
  - of Skajit formation ... 58, 97
  - of Stuver series ... 62, 97
  - of Totsen series ... 59–60, 97
- Corwin series, age of ... 74
  - character and occurrence of ... 72–73
  - coal bed and rocks of, plate showing ... 82
  - coal in ... 111–113
  - correlation of ... 74, 97
  - structure of ... 73

Page.

- Corwin mines, coal at, occurrence ... 112–113
  - coal from, analyses of ... 114
  - coal bed and rocks at ... 82
- Cosmos, Fort, temperature at ... 123–124
- Cotter, R. D., and Dyer, J. T., exploration by ... 28
- Coville, F. V., plants identified by ... 130–134
- Cretaceous rocks, description of ... 74–81
- Dall, W. H., exploration by ... 28
  - fossils identified by ... 96, 83
  - quoted on ground ice ... 91–92
  - reference to ... 71
  - work of ... 14
- Dawson, G. M., cited on age of Yukon Plateau ... 43
- Dawson trail, meteorologic observations on ... 125–127
- Dease and Simpson, exploration by ... 26
  - reference to ... 47, 49
- Delta at mouth of Colville River, description of ... 47–48
- Devonian rocks, description of ... 62–67
- Dikes on John River ... 53–54
- Distance, table of ... 37
- Dog sledding, description of ... 14–15
- Double Mountain, till terraces on ... 90
- Drainage of Arctic slope province ... 46–48
  - of Endicott Plateau ... 43
  - of Koyukuk province ... 45
- Dumars, H. D., fossils collected by ... 66, 71, 74, 114
- Dyer, Cape, rocks exposed at ... 67
- Dyer, J. T., and Cotter, R. D., exploration by ... 28
- Eagle Bluff and Ironside Bench, gold at, production of 102
- Edge, Joe, work of ... 12
- Eldridge, G. H., cited on Cantwell conglomerate ... 76
- Emma Creek, gold on, production of ... 102
- Endicott Mountains, Anaktuvuk series near ... 74–75
  - ancient plateau of, features of ... 42–43
  - Fickett series in ... 68
  - general features of ... 40–41
  - glaciation in, plates showing ... 58, 70, 84, 86
  - Lisburne limestone and Fickett series in, plate showing ... 42
  - Skajit formation in ... 56, 57
    - plate showing ... 56
  - Stuver series in ... 60, 61
  - views of ... 42, 46, 50, 56, 70, 84, 86
- Endicott Plateau, drainage of ... 43
  - features of ... 42–43
  - profile showing Yukon and Koyukuk plateaus and 44
  - view of ... 46
- Ericson, acknowledgments to ... 14
- Eskimo grave on Arctic coast, plate showing ... 96
- Explorations, account of ... 25–33
- Fickett series, age of ... 70–71
  - character and occurrence of ... 67–69
  - correlation of ... 71–72, 97
  - fossils from, list of ... 70
  - metalliferous mineralization in, zones of ... 106
  - moraine on, plate showing ... 86
  - quartz stringers in, view of ... 76
  - structure of ... 69–70
  - view of ... 42, 70
- Flats on Colville River, extent and character of ... 47
- Fontaine, W. M., fossils identified by ... 74
  - work of ... 14
- Fork Peak, till at ... 84
- Formations, table of ... 53
- Fort. *See* next word of name.
- Fossils from Arctic coast ... 96
  - from Cape Lisburne region ... 66
  - from Chandlar River gravels ... 66

Page.
Fossils from Colville series 83
  from Fickett series 70
  from Lisburne formation 65
  from Nanushuk series 80
  from Wainwright Inlet 74
  from Yukon Basin 81
Franklin, Sir John, exploration by 26
Geography of region, discussion of 38-50
Geology of region, discussion of 50-97
Gerdine, T. G., reference to 38
  work of 11
Girty, G. H., fossils identified by 66
  work of 14
Glacial deposits, description of 84-91
Glacial lakes, occurrence of 85
Glaciation, description of 84-91
  in upper John River Valley, plate showing 84
Gold in Koyukuk Basin, Hammond Creek 100
    John River 100-101
    Mascot Creek 100
    Myrtle Creek 99
    North Fork 100
    Slate Creek 99
    Tramway Bar 100
  occurrence of 98-104
    manner of 101
  production of 102
Gold Bench, gold at, production of 102
Gold Creek, antimony on 105
  gold on, production of 102
Greenstone. *See* Totsen series.
Grit. *See* Fickett series.
Ground ice, occurrence of 91-92
Gubik sand, occurrence of 93
Halkett, Cape, ground ice at 92
  view of 56
Hammond Creek, gold on 102
  nuggets from, size of 101-102
Hartman, G. H., plants collected by 130-134
  work of 11
Healey, M. A., work of 28
Hearne, Samuel, exploration by 25
Hokotena River, lead on 105
Holy Cross, meteorologic observations at 121
Hope Point, description of 51
  native population at 36
Howard, W. C., exploration by 29
  quoted on coal from Colville River 109
  reference to 67
  work of 11
Howard and Reed, reference to 72
Hunt, T. M., work of 11
Ice, breaking up of 15-16
Icy Cape, barrier reef and Eskimo grave near 96
Igneous rocks, table of 53
Inhabitants, number and conditions of 33-34, 35-36
Ironside Bench and Eagle Bluff, gold at, production of. 102
John River, coal on 107
  dikes on 53-54
  distances on, table showing 37
  Fickett series on, plate showing 70
  glacial deposits on 89
  name of, note on 17
  reconnaissance up 20-21
  Skajit limestone on, views of 50, 56
  till along 84-85
  Totsen series on 58, 59
  views on 50, 56

Page.
John River Valley, glaciation in, plate showing 84
  glacier in, remnant of 86
    remnant of, plate showing 86
  gold in 100-101
  moraine in 85
    plate showing 86
  topographic features of 43
  views of 46
Kennicott, Robert, cited on Devonian fossils from Lower Ramparts 66
  exploration by 28
Ketchum and Laberge, exploration by 28
Koog River, coal on 110
Kotzebue, O. von, exploration by 26
Kowak clay, occurrence of 92-93
Kowak River, temperature on 123-124
Koyukuk district, coal in 107
  copper in 104
  gold in, occurrence of 98-104
    production of 102
Koyukuk Plateau, profile showing Endicott and Yukon plateaus and 44
  relation to Endicott Plateau 42
Koyukuk province, drainage of 45
  general features of 44-45
Koyukuk River, coal from, analysis of 114
  coal on, occurrence of 107
  ice on, breaking up of 15-16
  meteorologic observations along 118-121
  placers on 35
  population along 33-34
  travel along, means of 34
Koyukuk series, character, occurrence, structure, and age of 77
Laberge and Ketchum, exploration by 28
Lagoons, occurrence of 50
Lead, occurrence of 105
Lewis, Cape, limestone at 67
Limestone. *See* Corwin series; Fickett series; Lisburne formation; Nanushuk series; Koyukuk series; Skajit formation.
Lisburne, Cape, coal from, analysis of 114
  coal south of 113-114
  coast between Point Barrow and, character of 49-50
  Recent deposits between Point Barrow and 96
  section south of, figure showing 40
  See also Cape Lisburne region.
Lisburne formation, age of 64-65
  character and occurrence of 62-64
  correlation of 65-67, 97
  distribution of 67
  fossils of, list of 65
  limestone of, views of 42, 56
  structure of 64
Lukeen, I. S., exploration by 27
McClure, Robert, exploration by 27
  reference to 48, 49
McConnell, R. G., cited on fossils from Lower Ramparts 66
  cited on fossils from Porcupine River 81
  exploration by 29
McDougald, John, acknowledgments to 18
McLanigan, S. C., exploration by 29
McMurray, ——, exploration by 27
Mackenzie, Alexander, exploration by 25
Mackenzie, D. A., reference to 35
Maddren, A. G., aid by 14
  cited on fossils at Cape Lisburne 67

Page.
Maddren, A. G., quoted on coal near Cape Lisburne .. 113
  reference to 66
Maguire, ——, exploration by 28
Malakoff, ——, exploration by 27
Marsh, S. J., and Carter, T. G., exploration by 30-31
Marshall, R. B., work of 12
Mascot Creek, gold on 100
Mendenhall, W. C., cited on geology on Alatna and Kowak rivers 51
  cited on glaciation on Alatna and Kowak rivers .. 90
  cited on igneous rock on Kanuti and Kowak rivers. 55
  exploration by 30
  reference to 71
Merrill, E. D., plants identified by 130
Mesozoic rocks, description of 72-81
Metalliferous mineralization, zones of 105-106
Meteorologic record for 1899, table showing 114-121
Mica-shist. *See* Skajit formation; Totsen series.
Michigan Creek, lead on 105
Mineral resources, discussion of 98-114
Moraine on John River, plate showing 86
Moraines, occurrence of 85-86, 87
Mounds near Colville River 94
Mountain province, description of 39-44
Myrtle Creek, gold on, occurrence of 100, 102
  gold on, production of 102
Mushing, description of 14
Nanushuk series, character and occurrence of 79
  coal in 107
  correlation of 88, 97
  fossils of, list of 80
  plate showing 80
  structure and age of 80
Natives, number and condition of 33, 35-36
North Fork Koyukuk River, gold on 100
Northwest coast, coal on 109-114
Norton, C. L., cited on coal from Corwin mines 112
Norton Sound, meteorologic observations on 121
Nuggets, size of 101
Nulato, meteorologic observations at 121
Nulato sandstone, fossils of 81
Operations, chronologic summary of 15-17
  plan of 18
Paleozoic rocks, description of 56-72
  structure of 55-56
Peneplain in Endicott Mountains 42-43
Peters, W. J., meteorologic observations by 122-123
  report on itinerary and topographic methods by .. 18-25
  work of 11
Philip, Gaston, meteorologic observations by 125-130
  work of 11
Phyllites. *See* Fickett series.
Pickarts Brothers, acknowledgments to 13
Placers on Koyukuk River 35
  See also Gold.
Plants collected, list of 130-134
Pleistocene deposits, description of 84-96
Pleistocene flats on Colville River, plates showing 96
Point. *See* next word of name.
Population, number and conditions of 33-34, 35-36
Porcupine Creek, gold on, production of 102
Precipitation at Uglaamie 123
Prindle, L. M., aid by 103
Pullen, exploration by 27
Putnam River. *See* Kowak River,
Quartz gash stringer, in Fickett series, view of 70
Quartz-mica-schist. *See* Totsen series.
Quartzite. *See* Fickett, Nanushuk, Stuver series.

Page.
Rainfall. *See* Precipitation.
Ray, P. H., work of 28
Raymond, C. W., work of 28
Reaburn, D. L., work of 11
Recent deposits, occurrence of 94-96
Reed, J. L., reference to 109
Reed and Howard, reference to 72
Reed, J. L., and Lucas, Walter, exploration by 81
Rivers. *See* Drainage.
Route, account of 18-24
Russell, Frank, exploration by 29
Sabine, Cape, rocks exposed at 73
  view of 56
St. Michael, meteorologic observations at 121
Sand. *See* Gubik sand.
Sandstone. *See* Anaktuvuk series; Bergman series; Colville series; Corwin series; Fickett series; Koyukuk series; Nanushuk series.
Schists, chloritic. *See* Fickett series.
Schrader, F. C., cited on benches on Koyukuk River. 43
  cited on Bettles series 58, 64, 65, 67
  cited on Chugach Plateau 42
  cited on fossils from Chandlar River gravels 65
  cited on glacial deposits in Chandlar River Basin. 89
  cited on gold at Slate Creek 99
  cited on intrusions in Koyukuk Basin 55
  cited on Lake quartz-schist of Chandlar River 59
  cited on Kenai series 107
  cited on Koyukuk Basin 44
  cited on Koyukuk Flats 45
  cited on Koyukuk series 76
  cited on Nulato sandstone 81
  cited on West Fork series of Chandlar River 71
  cited on Yukon Plateau 44
Schrader, F. C., and Spencer, A. C., cited on Chugach Plateau 42
  cited on Kennicott formation 74
Schuchert, Charles, fossil identified by 57, 65, 66, 70
  reference to 58
  work of 14
Sedimentary rocks, description of 55-96
  table of 53
Shale. *See* Bergman series; Colville series; Corwin series; Koyukuk series; Nanushuk series; Stuver series.
Silt. *See* Colville series.
Silurian rocks, description of 56-62
Simpson and Dease, exploration by 26
  reference to 47, 49
Skajit formation, age of 57-58
  character and occurrence of 56
  correlation of 58, 97
  structure of 56-57
  limestone of, views of 50, 56
Slate. *See* Bergman, Fickett, Nanushuk, Stuver series.
Slate Creek, gold on, occurrence of 99
  gold on, production of 102
Sledding, description of 14-15
Smyth, Cape, distances between Colville River and 88
  settlement at 36
Snow. *See* Precipitation.
Spencer, A. C., and Schrader, F. C., cited on Chugach Plateau 42
  cited on Kennicott formation 74
Spurr, J. E., cited on age of Yukon Plateau 43
  cited on Carboniferous fossils from Yukon Basin .. 71
  cited on Devonian in Kuskokwim region 67
  cited on Mission Creek series 76

Page.
Spurr, J. E., exploration by ... 30
  plan of exploration proposed by ... 12
Stanton, T. W., fossils identified by ... 76, 81
  work of ... 14
Steiger, George, analyses by ... 114
  work of ... 14
Stokes, H. N., work of ... 14
Stoney, G. M., cited on break-up of ice ... 16
  cited on coal on Colville River ... 109
  cited on Endicott Range ... 67
  meteorologic observations by ... 123–125
Streams. *See* Drainage.
Structure of Anaktuvuk series ... 75–76
  of Anaktuvuk series, plate showing ... 70
    profile showing ... 46
  of Bergman series ... 78
  of Colville series ... 82
    plate showing ... 80
  of Corwin series ... 73
  of Fickett series ... 69–70
  of Koyukuk series ... 77
  of Lisburne formation ... 64
  of Nanushuk series ... 80
    plate showing ... 80
  of Paleozoic rocks ... 55–56
  of Skajit formation ... 56–57
  of Stuver series ... 61–62
  of Totsen series ... 59
Stuver, C. H., work of ... 71
Stuver series, age and correlation of ... 62, 97
  character and occurrence of ... 60–61
  structure of ... 61–62
Temperature. *See* Climatic conditions.
Tertiary coastal plain, river bluffs in, view of ... 48
Tertiary rocks, description of ... 81–83
Thetis mines, coal at ... 111
Tides on Arctic coast ... 49
Till, occurrence of ... 84–90
Till Creek, till on ... 84
Timber, occurrence of ... 19
Topographic work, methods of ... 24–25
Totsen series, character and occurrence of ... 58–59
  structure and age of ... 59
  correlation of ... 59, 97

Page.
Totsen series, metalliferous mineralization in, zones of ... 105
Totsenbet River, name of, note on ... 58
  See John River.
Tramway Bar, coal near, analysis of ... 114
  coal near, occurrence of ... 107
  gold at, occurrence of ... 100
    production of ... 102
Transportation, method of ... 14–15
  method of, on Arctic coast ... 37
    on Koyukuk River ... 34
Travel. *See* Transportation.
Tuluga River, glacial deposits near ... 88
Turner, aid by ... 20
Turner, J. H., exploration by ... 29
  work of ... 11
Twelvemile Creek, gold on, production of ... 102
Uglaamie, precipitation at ... 123
  temperature observations at ... 122
Union Gulch, gold in, production of ... 102
  nugget from, size of ... 101
Wainwright Inlet, coal at ... 110
  coal from, analysis of ... 114
  Corwin series near ... 73
  fossils from, list of ... 74
Ward, L. F., fossils identified by ... 74
  work of ... 14
Weather. *See* Climatic conditions.
White, David, fossils identified by ... 71, 114
Wight, W. F., plants identified by ... 130–134
Wild Creek, lead on ... 105
Willow Creek, till near ... 87–88
Wind. *See* Climatic conditions.
Woolfe, H. D., cited on coal at Wainwright Inlet ... 110
  fossils collected by ... 74
  quoted on coal at Cape Beaufort ... 111
Work, methods of ... 14–18
Yukon, Fort, meteorologic observations at ... 115
Yukon Basin, fossils from ... 81
Yukon Plateau, age of ... 43
  profile showing Endicott and Koyukuk plateaus and ... 44
Yukon River, meteorologic observations on ... 121
Zagoskin, A., exploration by ... 27

O

SCROPHULARIACEÆ. (Figwort family.)

Pedicularis.
At camp, July 21.
Pedicularis verticillata L.
At camp, Anaktuvuk River, August 5.

CICHORIACEÆ. (Chicory family.)

Taraxacum.
At camp, Colville delta, August 14.
Crepis nana Richards.
At camp, August 6.

ASTERACEÆ. (Aster family.)

Solidago multiradiata Ait.
At camp, Anaktuvuk River, August 5.
Aster.
At camp, Anaktuvuk River, August 5.
Aster sibiricus L.
At camp, August 12.
Erigeron.
At camp, John River, July 10.
Tanacetum.
At camp, August 12.
Artemisia.
At camp, John River, July 10.
Artemisia norvegica Fries.
At camp, August 6.
Artemisia tilesii Ledeb.
At camp, August 12.
Petasites.
At camp, August 12.
Arnica.
At camp, John River, July 12.
Arnica.
At camp, August 12.
Arnica.
At camp, Arctic slope, July 21.
Arnica lessingii (Torr. and Gr.) Greene.
At camp, Anaktuvuk River, August 5.
Senecio.
Point Barrow, September 4.
Senecio lugens Richards.
At camp, August 6.

INDEX.

Page.
Abbe, Cleveland, jr., aid by 115
Alaska, investigations in 11-14
  outline map of 11
Alaska Commercial Company, acknowledgments to 13
Alatna River, gold-bearing ore on 102-104
  name of, note on 20
  reconnaissance up 20
Allen, H. T., cited on Endicott Mountains 40
  exploration by 29
Allen River, name of, note on 20
  See Alatna River.
Amphibole-schist. *See* Totsen series.
Anaktuvuk Pass, glacial deposits near 86
  glacial lakes at 85
  section west of, figure showing 51
  view near 56
Anaktuvuk Plateau, extent and character of 45-46
  view showing 42
Anaktuvuk River, Anaktuvuk series on, plate showing 70
  coal from, analysis of 114
  coal on, occurrence of 107
  Colville series on 82
  distances along, table showing 37
  fossils from, list of 80
  glacial deposits on 86-88
  Lisburne formation near 63
  Nanushuk series on 79
    plate showing 80
  profile across 46
  Recent deposits along 94
  topographic features along 48
Anaktuvuk series, age and correlation of 76, 97
  character and occurrence of 74-75
  structure of 75-76
    plate showing 70
    profile showing 46
Analyses, coal 114
Andreafski, meteorologic observations at and near 121
Antimony, occurrence of 105
Arctic coast, barrier reef and Eskimo grave near, plate showing 96
  character of 48-50
  coal on 107-109
  distances along, table showing 38
  fossils from 96
  inhabitants along, number and condition of 35-36
  meteorologic observations between Bergman and 127-130
  Recent deposits along 95-96
  view of 50
Arctic Coastal Plain, edge of, view of 50
  extent and character of 46, 81

Page.
Arctic Ocean, depth of 49
Arctic slope province, coast line of 48-50
  drainage of 46-48
  extent and character of 45-46
Area discussed, climatic conditions in 114-130
  geography of 38-50
  geologic history of 52-55
  geologic map of 40
  geology of 50-97
  location and general features of 38-39
  mineral resources of 98-114
  plants collected in 130-134
  topographic map of 38
Arkose. *See* Anaktuvuk series; Koyukuk series.
Barometer. *See* Climatic conditions.
Barrier reef on Arctic coast, plate showing 96
Barrow, Point, coast between Cape Lisburne and, character of 49-50
  coast between Colville River and, character of 48-49
  Recent deposits between Colville River and 95
    between Cape Lisburne and 96
  settlement at 36
  topographic features at 49
  trip from Bettles to, account of 21-24
Beaufort, Cape, coal at, occurrence of 110-111
  coal from, analysis of 114
  rocks exposed at 73
  topographic features near 50
Beechey, F. W., exploration by 26
Bell, J., exploration by 27
Bennett, Ben, work of 11
Bergman, glacial deposits near 90
  meteorologic observations between Arctic coast and 127-130
Bergman series, age of 78-79
  character and occurrence of 77-78
  correlation of 97
  structure of 78
Bettles, G. C., acknowledgments to 13
Bettles, trip to Point Barrow from, account of 21-24
Bibliography 31-33
Brauer, Charles, acknowledgments to 14
  reference to 36
Bremner, John, river named for 17
Brooks, A. H., cited on fossils from Glacier Bay limestone 57
  cited on fossils from southeastern Alaska 67
  letter of transmittal by 9
  work of 12
Burlingame, E. E. & Co., work of 14
Busby, E. S., acknowledgments to 18
Cache Lake, view from 56
California Creek, gold on, production of 102

Page.
Campbell, Robert, exploration by 27
Camping, manner of 15
Canadian Development Company, acknowledgments to 13
Cantwell, J. C., exploration by 29
Cape. *See* next word of name.
Cape Lisburne region, Fickett series in 72
  fossils from, list of 66
  geologic section in 41
  map of 44
Carboniferous rocks, description of 67–72
Carter, T. G., and Marsh, S. J., exploration by 30–31
Chandlar Basin, copper in 104
Chandlar River, meteorologic observations on 115–118
Chandlar River gravels, fossils from, list of 66
Chert. *See* Nanushuk series.
Chloritic schists. *See* Fickett series.
Clara Creek, gold on, production of 102
  nugget from, size of 101
Clay. *See* Kowak clay.
Climatic conditions, tables showing 114–130
Coal, analysis of 114
  occurrence of 106–114
Coast along Arctic Ocean, character of 48–50
Coastal region, recent deposits in 95–96
Collier, A. J., cited on fossils of Seward Peninsula 58
  reference to 71
Collinson, R., exploration by 27
Colville delta, extent and character of 47–48
Colville Flats, extent and character of 47
Colville River, bluffs on, view of 48
  coal from, analysis of 114
  coal on, occurrence of 107–109
  coast between Point Barrow and, character of 48–49
  distances along, table showing 37
    between Cape Smyth and 38
  fossil locality on, view of 84
  mounds near 94
  Pleistocene flats on, plate showing 96
  Recent deposits along 94–95
  topographic features along 46–48, 81, 94
Colville series, character and occurrence of 81
  coal in 107–109
  correlation of 97
  fossil locality on, view of 84
  fossils from, list of 83
  river bluffs in, view of 48
  structure of 82
    plate showing 82
Conglomerate. *See* Bergman, Fickett, Stuver series.
Contact Creek, Lisburne formation near 63, 64
  moraine in valley of 85
Cook, James, exploration by 25
Copper, occurrence of 104
Correlation of Anaktuvuk series 76, 97
  of Corwin series 74, 97
  of Fickett series 71–72, 97
  of formations, table showing 97
  of Lisburne formation 65–67, 97
  of Nanushuk series 80–81, 97
  of Skajit formation 58, 97
  of Stuver series 62, 97
  of Totsen series 59–60, 97
Corwin series, age of 74
  character and occurrence of 72–73
  coal bed and rocks of, plate showing 82
  coal in 111–113
  correlation of 74, 97
  structure of 73

Page.
Corwin mines, coal at, occurrence 112–113
  coal from, analyses of 114
  coal bed and rocks at 82
Cosmos, Fort, temperature at 123–124
Cotter, R. D., and Dyer, J. T., exploration by 28
Coville, F. V., plants identified by 130–134
Cretaceous rocks, description of 74–81
Dall, W. H., exploration by 28
  fossils identified by 96, 83
  quoted on ground ice 91–92
  reference to 71
  work of 14
Dawson, G. M., cited on age of Yukon Plateau 43
Dawson trail, meteorologic observations on 125–127
Dease and Simpson, exploration by 26
  reference to 47, 49
Delta at mouth of Colville River, description of 47–48
Devonian rocks, description of 62–67
Dikes on John River 53–54
Distance, table of 37
Dog sledding, description of 14–15
Double Mountain, till terraces on 90
Drainage of Arctic slope province 46–48
  of Endicott Plateau 43
  of Koyukuk province 45
Dumars, H. D., fossils collected by 66, 71, 74, 114
Dyer, Cape, rocks exposed at 67
Dyer, J. T., and Cotter, R. D., exploration by 28
Eagle Bluff and Ironside Bench, gold at, production of 102
Edge, Joe, work of 12
Eldridge, G. H., cited on Cantwell conglomerate 76
Emma Creek, gold on, production of 102
Endicott Mountains, Anaktuvuk series near 74–75
  ancient plateau of, features of 42–43
  Fickett series in 68
  general features of 40–41
  glaciation in, plates showing 58, 70, 84, 86
  Lisburne limestone and Fickett series in, plate showing 42
  Skajit formation in 56, 57
    plate showing 56
  Stuver series in 60, 61
  views of 42, 46, 50, 56, 70, 84, 86
Endicott Plateau, drainage of 43
  features of 42–43
  profile showing Yukon and Koyukuk plateaus and 44
  view of 46
Ericson, acknowledgments to 14
Eskimo grave on Arctic coast, plate showing 96
Explorations, account of 25–33
Fickett series, age of 70–71
  character and occurrence of 67–69
  correlation of 71–72, 97
  fossils from, list of 70
  metalliferous mineralization in, zones of 106
  moraine on, plate showing 86
  quartz stringers in, view of 76
  structure of 69–70
  view of 42, 70
Flats on Colville River, extent and character of 47
Fontaine, W. M., fossils identified by 74
  work of 14
Fork Peak, till at 84
Formations, table of 53
Fort. *See* next word of name.
Fossils from Arctic coast 96
  from Cape Lisburne region 66
  from Chandlar River gravels 66

Page.
Fossils from Colville series 83
  from Fickett series 70
  from Lisburne formation 65
  from Nanushuk series 80
  from Wainwright Inlet 74
  from Yukon Basin 81
Franklin, Sir John, exploration by 26
Geography of region, discussion of 38–50
Geology of region, discussion of 50–97
Gerdine, T. G., reference to 38
  work of 11
Girty, G. H., fossils identified by 66
  work of 14
Glacial deposits, description of 84–91
Glacial lakes, occurrence of 85
Glaciation, description of 84–91
  in upper John River Valley, plate showing 84
Gold in Koyukuk Basin, Hammond Creek 100
    John River 100–101
    Mascot Creek 100
    Myrtle Creek 99
    North Fork 100
    Slate Creek 99
    Tramway Bar 100
  occurrence of 98–104
    manner of 101
  production of 102
Gold Bench, gold at, production of 102
Gold Creek, antimony on 105
  gold on, production of 102
Greenstone. *See* Totsen series.
Grit. *See* Fickett series.
Ground ice, occurrence of 91–92
Gubik sand, occurrence of 93
Halkett, Cape, ground ice at 92
  view of 56
Hammond Creek, gold on 102
  nuggets from, size of 101–102
Hartman, G. H., plants collected by 130–134
  work of 11
Healey, M. A., work of 28
Hearne, Samuel, exploration by 25
Hokotena River, lead on 105
Holy Cross, meteorologic observations at 121
Hope Point, description of 51
  native population at 36
Howard, W. C., exploration by 29
  quoted on coal from Colville River 109
  reference to 67
  work of 11
Howard and Reed, reference to 72
Hunt, T. M., work of 11
Ice, breaking up of 15–16
Icy Cape, barrier reef and Eskimo grave near 96
Igneous rocks, table of 53
Inhabitants, number and conditions of 33–34, 35–36
Ironside Bench and Eagle Bluff, gold at, production of. 102
John River, coal on 107
  dikes on 53–54
  distances on, table showing 37
  Fickett series on, plate showing 70
  glacial deposits on 89
  name of, note on 17
  reconnaissance up 20–21
  Skajit limestone on, views of 50, 56
  till along 84–85
  Totsen series on 58, 59
  views on 50, 56

Page.
John River Valley, glaciation in, plate showing 84
  glacier in, remnant of 86
    remnant of, plate showing 86
  gold in 100–101
  moraine in 85
    plate showing 86
  topographic features of 43
  views of 46
Kennicott, Robert, cited on Devonian fossils from Lower Ramparts 66
  exploration by 28
Ketchum and Laberge, exploration by 28
Koog River, coal on 110
Kotzebue, O. von, exploration by 26
Kowak clay, occurrence of 92–93
Kowak River, temperature on 123–124
Koyukuk district, coal in 107
  copper in 104
  gold in, occurrence of 98–104
    production of 102
Koyukuk Plateau, profile showing Endicott and Yukon plateaus and 44
  relation to Endicott Plateau 42
Koyukuk province, drainage of 45
  general features of 44–45
Koyukuk River, coal from, analysis of 114
  coal on, occurrence of 107
  ice on, breaking up of 15–16
  meteorologic observations along 118–121
  placers on 35
  population along 33–34
  travel along, means of 34
Koyukuk series, character, occurrence, structure, and age of 77
Laberge and Ketchum, exploration by 28
Lagoons, occurrence of 50
Lead, occurrence of 105
Lewis, Cape, limestone at 67
Limestone. *See* Corwin series; Fickett series; Lisburne formation; Nanushuk series; Koyukuk series; Skajit formation.
Lisburne, Cape, coal from, analysis of 114
  coal south of 113–114
  coast between Point Barrow and, character of 49–50
  Recent deposits between Point Barrow and 96
  section south of, figure showing 40
  See also Cape Lisburne region.
Lisburne formation, age of 64–65
  character and occurrence of 62–64
  correlation of 65–67, 97
  distribution of 67
  fossils of, list of 65
  limestone of, views of 42, 56
  structure of 64
Lukeen, I. S., exploration by 27
McClure, Robert, exploration by 27
  reference to 48, 49
McConnell, R. G., cited on fossils from Lower Ramparts 66
  cited on fossils from Porcupine River 81
  exploration by 29
McDougald, John, acknowledgments to 18
McLanigan, S. C., exploration by 29
McMurray, ———, exploration by 27
Mackenzie, Alexander, exploration by 25
Mackenzie, D. A., reference to 35
Maddren, A. G., aid by 14
  cited on fossils at Cape Lisburne 67

Page.
Maddren, A. G., quoted on coal near Cape Lisburne .. 113
  reference to 66
Maguire, ——, exploration by 28
Malakoff, ——, exploration by 27
Marsh, S. J., and Carter, T. G., exploration by 30–31
Marshall, R. B., work of 12
Mascot Creek, gold on 100
Mendenhall, W. C., cited on geology on Alatna and Kowak rivers 51
  cited on glaciation on Alatna and Kowak rivers .. 90
  cited on igneous rock on Kanuti and Kowak rivers. 55
  exploration by 30
  reference to 71
Merrill, E. D., plants identified by 130
Mesozoic rocks, description of 72–81
Metalliferous mineralization, zones of 105–106
Meteorologic record for 1899, table showing 114–121
Mica-shist. *See* Skajit formation; Totsen series.
Michigan Creek, lead on 105
Mineral resources, discussion of 98–114
Moraine on John River, plate showing 86
Moraines, occurrence of 85–86, 87
Mounds near Colville River 94
Mountain province, description of 39–44
Myrtle Creek, gold on, occurrence of 100, 102
  gold on, production of 102
Mushing, description of 14
Nanushuk series, character and occurrence of 79
  coal in 107
  correlation of 88, 97
  fossils of, list of 80
  plate showing 80
  structure and age of 80
Natives, number and condition of 33, 35–36
North Fork Koyukuk River, gold on 100
Northwest coast, coal on 109–114
Norton, C. L., cited on coal from Corwin mines 112
Norton Sound, meteorologic observations on 121
Nuggets, size of 101
Nulato, meteorologic observations at 121
Nulato sandstone, fossils of 81
Operations, chronologic summary of 15–17
  plan of 18
Paleozoic rocks, description of 56–72
  structure of 55–56
Peneplain in Endicott Mountains 42–43
Peters, W. J., meteorologic observations by 122–123
  report on itinerary and topographic methods by .. 18–25
  work of 11
Philip, Gaston, meteorologic observations by 125–130
  work of 11
Phyllites. *See* Fickett series.
Pickarts Brothers, acknowledgments to 13
Placers on Koyukuk River 35
  See also Gold.
Plants collected, list of 130–134
Pleistocene deposits, description of 84–96
Pleistocene flats on Colville River, plates showing 96
Point. *See* next word of name.
Population, number and conditions of 33–34, 35–36
Porcupine Creek, gold on, production of 102
Precipitation at Uglaamie 123
Prindle, L. M., aid by 103
Pullen, exploration by 27
Putnam River. *See* Kowak River,
Quartz gash stringer, in Fickett series, view of 70
Quartz-mica-schist. *See* Totsen series.
Quartzite. *See* Fickett, Nanushuk, Stuver series.

Page.
Rainfall. *See* Precipitation.
Ray, P. H., work of 28
Raymond, C. W., work of 28
Reaburn, D. L., work of 11
Recent deposits, occurrence of 94–96
Reed, J. L., reference to 109
Reed and Howard, reference to 72
Reed, J. L., and Lucas, Walter, exploration by 31
Rivers. *See* Drainage.
Route, account of 18–24
Russell, Frank, exploration by 29
Sabine, Cape, rocks exposed at 73
  view of 56
St. Michael, meteorologic observations at 121
Sand. *See* Gubik sand.
Sandstone. *See* Anaktuvuk series: Bergman series; Colville series; Corwin series; Fickett series; Koyukuk series; Nanushuk series.
Schists, chloritic. *See* Fickett series.
Schrader, F. C., cited on benches on Koyukuk River. 43
  cited on Bettles series 58, 64, 65, 67
  cited on Chugach Plateau 42
  cited on fossils from Chandlar River gravels 65
  cited on glacial deposits in Chandlar River Basin. 89
  cited on gold at Slate Creek 99
  cited on intrusions in Koyukuk Basin 55
  cited on Lake quartz-schist of Chandlar River 59
  cited on Kenai series 107
  cited on Koyukuk Basin 44
  cited on Koyukuk Flats 45
  cited on Koyukuk series 76
  cited on Nulato sandstone 81
  cited on West Fork series of Chandlar River 71
  cited on Yukon Plateau 44
Schrader, F. C., and Spencer, A. C., cited on Chugach Plateau 42
  cited on Kennicott formation 74
Schuchert, Charles, fossil identified by 57, 65, 66, 70
  reference to 58
  work of 14
Sedimentary rocks, description of 55–96
  table of 53
Shale. *See* Bergman series; Colville series; Corwin series; Koyukuk series; Nanushuk series; Stuver series.
Silt. *See* Colville series.
Silurian rocks, description of 56–62
Simpson and Dease, exploration by 26
  reference to 47, 49
Skajit formation, age of 57–58
  character and occurrence of 56
  correlation of 58, 97
  structure of 56–57
  limestone of, views of 50, 56
Slate. *See* Bergman, Fickett, Nanushuk, Stuver series.
Slate Creek, gold on, occurrence of 99
  gold on, production of 102
Sledding, description of 14–15
Smyth, Cape, distances between Colville River and 88
  settlement at 36
Snow. *See* Precipitation.
Spencer, A. C., and Schrader, F. C., cited on Chugach Plateau 42
  cited on Kennicott formation 74
Spurr, J. E., cited on age of Yukon Plateau 43
  cited on Carboniferous fossils from Yukon Basin .. 71
  cited on Devonian in Kuskokwim region 67
  cited on Mission Creek series 76

Page.
Spurr, J. E., exploration by ... 30
  plan of exploration proposed by ... 12
Stanton, T. W., fossils identified by ... 76, 81
  work of ... 14
Steiger, George, analyses by ... 114
  work of ... 14
Stokes, H. N., work of ... 14
Stoney, G. M., cited on break-up of ice ... 16
  cited on coal on Colville River ... 109
  cited on Endicott Range ... 67
  meteorologic observations by ... 123–125
Streams. *See* Drainage.
Structure of Anaktuvuk series ... 75–76
  of Anaktuvuk series, plate showing ... 70
    profile showing ... 46
  of Bergman series ... 78
  of Colville series ... 82
    plate showing ... 80
  of Corwin series ... 73
  of Fickett series ... 69–70
  of Koyukuk series ... 77
  of Lisburne formation ... 64
  of Nanushuk series ... 80
    plate showing ... 80
  of Paleozoic rocks ... 55–56
  of Skajit formation ... 56–57
  of Stuver series ... 61–52
  of Totsen series ... 59
Stuver, C. H., work of ... 71
Stuver series, age and correlation of ... 62, 97
  character and occurrence of ... 60–61
  structure of ... 61–62
Temperature. *See* Climatic conditions.
Tertiary coastal plain, river bluffs in, view of ... 48
Tertiary rocks, description of ... 81–83
Thetis mines, coal at ... 111
Tides on Arctic coast ... 49
Till, occurrence of ... 84–90
Till Creek, till on ... 84
Timber, occurrence of ... 19
Topographic work, methods of ... 24–25
Totsen series, character and occurrence of ... 58–59
  structure and age of ... 59
  correlation of ... 59, 97

Page.
Totsen series, metalliferous mineralization in, zones of ... 105
Totsenbet River, name of, note on ... 58
  See John River.
Tramway Bar, coal near, analysis of ... 114
  coal near, occurrence of ... 107
  gold at, occurrence of ... 100
    production of ... 102
Transportation, method of ... 14–15
  method of, on Arctic coast ... 37
    on Koyukuk River ... 34
Travel. *See* Transportation.
Tuluga River, glacial deposits near ... 88
Turner, aid by ... 20
Turner, J. H., exploration by ... 29
  work of ... 11
Twelvemile Creek, gold on, production of ... 102
Uglaamie, precipitation at ... 123
  temperature observations at ... 122
Union Gulch, gold in, production of ... 102
  nugget from, size of ... 101
Wainwright Inlet, coal at ... 110
  coal from, analysis of ... 114
  Corwin series near ... 73
  fossils from, list of ... 74
Ward, L. F., fossils identified by ... 74
  work of ... 14
Weather. *See* Climatic conditions.
White, David, fossils identified by ... 71, 114
Wight, W. F., plants identified by ... 130–134
Wild Creek, lead on ... 105
Willow Creek, till near ... 87–88
Wind. *See* Climatic conditions.
Woolfe, H. D., cited on coal at Wainwright Inlet ... 110
  fossils collected by ... 74
  quoted on coal at Cape Beaufort ... 111
Work, methods of ... 14–18
Yukon, Fort, meteorologic observations at ... 115
Yukon Basin, fossils from ... 81
Yukon Plateau, age of ... 43
  profile showing Endicott and Koyukuk plateaus and ... 44
Yukon River, meteorologic observations on ... 121
Zagoskin, A., exploration by ... 27

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